UNCLASSIFIED

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

AD NUMBER

AD-007 868

CLASSIFICATION CHANGES

TO **UNCLASSIFIED**

FROM **CONFIDENTIAL**

19990211 115

AUTHORITY

ARRADCOM Ltr; Sep 8, 1981

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER

AD-007 868

NEW LIMITATION CHANGE

TO

DISTRIBUTION STATEMENT - A

Approved for public release;
distribution is unlimited.

LIMITATION CODE: 1

FROM

NO PRIOR DoD DISTR SCTY CNTRL ST'MT ASSIGNED

AUTHORITY

ARRADCOM Ltr; Sep 8, 1981

THIS PAGE IS UNCLASSIFIED

REPRODUCTION QUALITY NOTICE

This document is the best quality available. The copy furnished to DTIC contained pages that may have the following quality problems:

- Pages smaller or larger than normal.
- Pages with background color or light colored printing.
- Pages with small type or poor printing; and or
- Pages with continuous tone material or color photographs.

Due to various output media available these conditions may or may not cause poor legibility in the microfiche or hardcopy output you receive.

☐ If this block is checked, the copy furnished to DTIC contained pages with color printing, that when reproduced in Black and White, may change detail of the original copy.

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200,20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE,

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED,

UNCLASSIFIED

AD 7868

CLASSIFICATION CHANGED
TO: UNCLASSIFIED
FROM: CONFIDENTIAL
AUTHORITY:
ARRADCOM
ITL, 8 Sept. 81

UNCLASSIFIED

[redacted]
SECURITY INFORMATION

QUARTERLY PROGRESS REPORT NO. 2
ON
STINGER 37-MM ADAPTATION STUDY

COVERING PERIOD 1 SEPTEMBER 1952 TO 30 NOVEMBER 1952

PREPARED FOR

NEW YORK ORDNANCE DISTRICT
CONTRACT DA-30-069-ORD-607

SPERRY GYROSCOPE COMPANY
DIVISION OF THE SPERRY CORPORATION
GREAT NECK, NEW YORK

SPERRY REPORT NO. 5282-7144
JANUARY 1953

COPY NO. 31
[redacted]

SECURITY INFORMATION

[redacted]
Security Information

CLASSIFICATION NOTICE

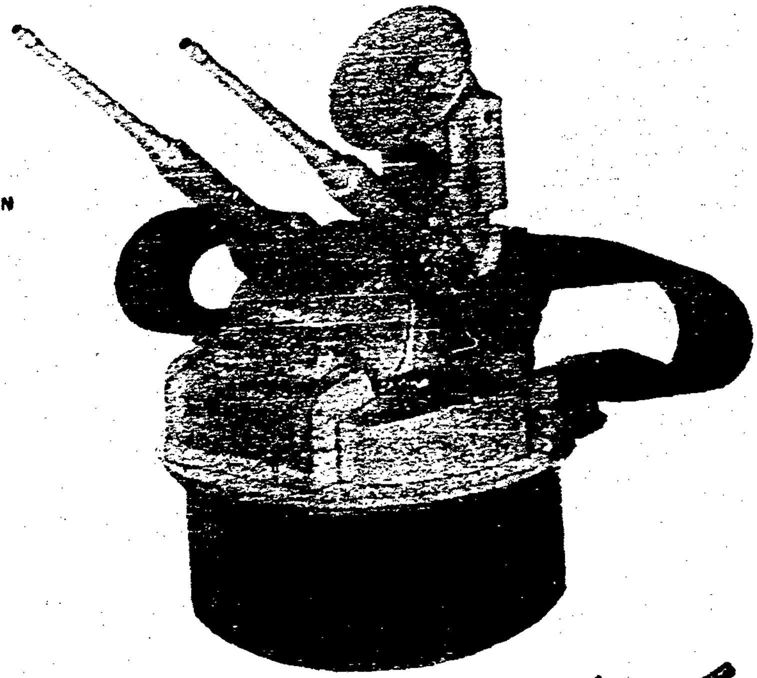
This document is classified as CONFIDENTIAL and contains information affecting the national defense of the United States within the meaning of the Espionage Act, 50 U.S.C, 31 and 32, as amended. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

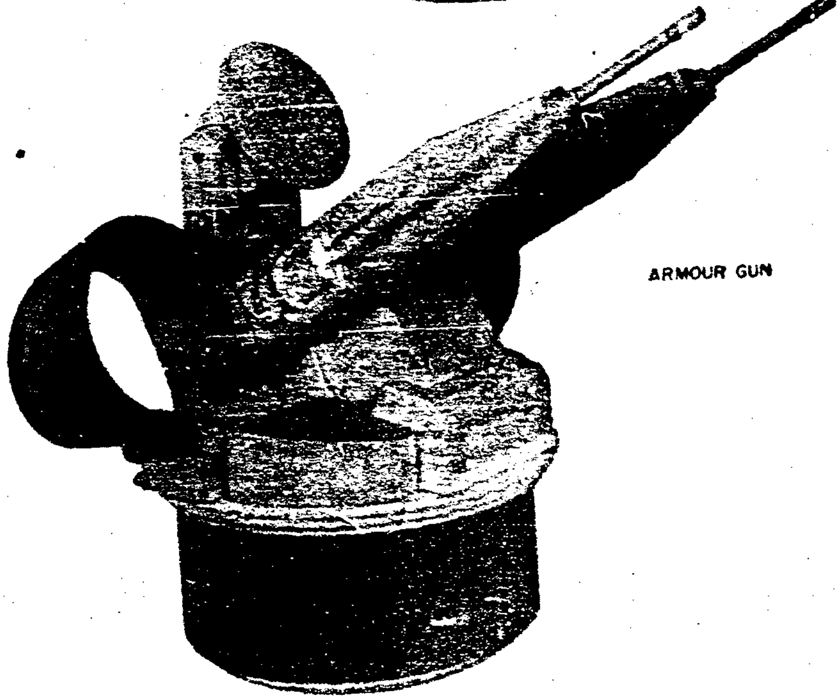
SECURITY INFORMATION

[redacted]

[redacted]
SECURI[redacted]NFORMATIO

DIXON GUN





ARMOUR GUN

FRONTISPIECE
37-MM STINGER MOCK-UP

[redacted]L

SECURITY INFORMATION

TABLE OF CONTENTS

Section			Page
I		INTRODUCTION	1
	A.	General	1
	B.	System Studies	4
	C.	Radar Studies	5
	D.	Computer Studies	6
	E.	Turret and Vehicle Studies	10
II		TRIPS AND VISITS	13
III		COMPUTER STUDIES	15
	A.	Main Section, Model 1 Computer	15
	B.	Main Section, Model 2 Computer	15
	C.	Rotating Element, Model 2 Computer	27
	D.	Main Section, Model 3 Computer	28
	E.	Ballistic Mechanism	28
	F.	Precession Mechanism Model 2 and 3 Computers	28
	G.	Precession Mechanism Model 1 Computer	32
	H.	Potentiometer Studies	35
	I.	Precession Mechanism Study	39
	J.	TM Computer Studies, Model 1 and 2 Computers	46
	K.	TM Computer Studies, Model 3 Computer	53

TABLE OF CONTENTS (Cont.)

Section Page

L. Accuracy Studies 54

M. Parameter (Limit) Study 56

IV SERVOS 75

A. Introduction 75

B. Basic Requirements 75

C. Stroking and Control Mechanism 78

D. Dynamic Considerations 82

E. Breadboard Assembly 91

F. Future Activity 92

V TURRET AND VEHICLE STUDIES 93

A. Ammunition Storage, Ammunition Feed, and Gun Mounting Studies 93

B. Structure Studies 104

C. Vehicle 112

D. Electrical Power Supply 113

Appendix

A A GLOSSARY OF DIRECTOR SYMBOLS

B A GLOSSARY OF SYMBOLS USED IN ANALYTIC STUDIES OF THE DIRECTOR 122

C ILLUSTRATION IDENTIFICATION 125

LIST OF TABLES

Table		Page
1-1	Differences in Models of the TM Computer	9
3-1	Computer Sensitivity Parameters	73
3-2	Differential Ballistic Parameters	73
3-3	Computer Tracking Parameters	74
5-1	Fourier Series Coefficients	104

LIST OF ILLUSTRATIONS*

Figure No.	Title
Frontispiece	37-mm Stinger Mock-up
3-1	Data Flow of Model 2 Computer
3-2	Magnetic Torque Mechanism
3-3	Precession Torque Multiplier Breadboard
3-4	Precession Mechanism - Ten-Turn Helipot Model 1 Computer
3-5	Precession Mechanism - Ten-Turn Helipot Model 1 Computer
3-6	Precession Mechanism - Twenty-Turn Helipot Model 1 Computer
3-7	LPR Mechanism Twenty-Turn Helipot
3-8	LPR Mechanism Twenty-Turn Helipot
3-9	Potentiometer Mounting in VPR Servo
3-10	Zero Rate Adjustment
3-11	1000 Ohm - Ten-Turn, Slide-Wire Potentiometer
3-12	Three-turn Helipot
3-13	Schematic Precession Mechanism for T26 Computer
3-14	Schematic Precession Torque Multiplier for 37-mm Stinger
3-15	Arrangement of Proposed Precession Torque Multiplier

---

* Except for the Frontispiece, illustrations are presented in order by figure number at the conclusion of the text.

LIST OF ILLUSTRATIONS (Cont.)

Figure No.	Title
3-16	Study of Precession Servo Linkage and Spring
3-17	Precession Torque Multiplier
3-18	D_o Gear Train
3-19	TM Computer Parameters
3-20	Lead Angle Curves for 800 mph Courses
4-1	Azimuth Power Control Package
4-2	Azimuth Power Control Servo Block Diagram
4-3	Azimuth Power Control Servo Block Diagram
4-4	Azimuth Power Control Servo Block Diagram with Known Coefficients Inserted
5-1	Ammunition Racking System Mock-up
5-2	Sprocket Force-Time Graph for a 28 Volt D-C Motor
5-3	Sprocket Force-Time Graph for a 115-volt, 400-cycle, Three-Phase Motor
5-4	Booster for a 500 Rounds per Minute Gun
5-5	Mounting of Armour Gun with Welded Cradle
5-6	Armour Gun Bolted to Torque Tube
5-7	Dixon Gun Mounted in cradle Bolted to Torque Tube
5-8	Spiral Equilibrator Spring for Armour Gun
5-9	Spiral Equilibrator Spring for Dixon Gun
5-10	Helical Equilibrator Spring of Armour Gun
5-11	Recoil Force - Time Graph for Armor Gun

LIST OF ILLUSTRATIONS (Cont.)

Figure No.	Title
5-12	Upper Structure Layout
5-13	Rear Door Lock
5-14	Hull Clearance Between Stinger and Vehicle
5-15	Firewall Clearance Between Stinger and Vehicle
5-16	Main Bearing Construction
5-17	Deflection of Balls in Azimuth Bearing
5-18	Foundation Modulus
5-19	Modification of Vehicle for Support of Stinger
5-20	Gas Turbine - Generator Set Mounted on Sponson

SECTION I

INTRODUCTION

A. GENERAL

This is the second in a series of quarterly progress reports being prepared for the New York Ordnance District by the Sperry Gyroscope Company on Contract DA-30-069-ORD-607. These reports describe the progress being made on the feasibility of adapting Stinger type fire control and turret design to the new 37-mm gun. The program for this contract was outlined in the proposal (Negotiation No. 0.16434-2) dated January, 1952.

The Stinger is a short range antiaircraft artillery weapon designed primarily for use against low flying targets having speeds up to 800 miles an hour. Originally designed to use four caliber .60 guns, the system is contained in a turret-type structure about 6 feet in diameter and about 11 feet high when mounted in a tank. With minor alterations, the turret-type structure can be mounted on a trailed or fixed mount.

Weighing between two and three tons, the Stinger consists of several separate assemblies which would make air transport feasible in an early phase. Director T42 consisting of Radar Tracker T8, an optical system, and a gyroscope type

Computer T26, provides various combinations of radar and optical searching and tracking which can be used depending on the tactical situation. The optical system could also be used to direct ground support fire.

This study has for its objective a gun mount similar to Stinger mount T135 except that it will carry two newly designed 37-mm guns instead of four caliber .60 weapons. Two versions of the new gun are under development for other contracts; the T172 (Armour) and the T37 (Dixon). Both guns will be considered during the course of this study. Modification of the mount to accept the new guns will involve strengthening the structure, the gearing, and the power controls T29, and providing an ammunition feed and storage system.

A study of the vehicle used for the Gun, Twin 40-mm Self-Propelled T141 to determine its feasibility for Stinger is to be made. Brief space studies will be made to determine modifications of the turret compartment and cockpit of the vehicle. The vehicle problem will also include studies of power supply requirements.

A major portion of the contract involves the adaptation of Director T42 to the 37-mm HE shell T81. Although the tactical role of the new equipment is to be the same as for the Director T42, the ballistics will be changed considerably and the effective firing range increased from 2000 yards to 4500 yards. The ballistics change will affect only the Computer T26 whereas the increased range will mean new requirements for both the Computer T26 and the Tracker T8. Increased pickup range for the radar tracker is expected through the use of improved r-f components and improved receiver techniques.

The principal emphasis in the fire control study will be placed upon increasing the accuracy. The higher maximum time-of-flight and range both require greater precision in the rate computation. At the same time, however, there will be emphasis upon simplification based on field experience with the two Stinger pilot models. Different degrees of computer redesign will be compared analytically to determine the extent of modification which is justified for fire control effectiveness.

While consideration will be given to the matter of minimizing redesign, director accuracy will not be compromised. The simplification objectives will limit the amount of existing design which can be salvaged. While some design studies and testing are involved in this contract, the number and scope will be sufficient only to decide feasibility.

B. SYSTEM STUDIES

The new work to be done with respect to the overall Stinger system is concerned with the possible simplification of the unit. Such simplification would be effected by attempting to reduce the number of components and by simplifying operation, maintenance, and manufacture. With this aim in mind, the following changes are proposed for consideration. Details of the effect of these changes on the computer are discussed in Section III.

(a) Eliminate stadiametric ranging; use tracer fire with a speed ring sight as a secondary mode or allow the target selector operator to set in estimated range while the turret operator tracks optically in azimuth and elevation.

(b) Eliminate the manual radar range and manual radar angular tracking modes.

(c) Eliminate the tracking scope.

(d) Improve the PPI presentation with respect to resolution and persistence, and eliminate stereo presentation.

(e) Eliminate inclinometers of the present design, and substitute either a pendulum or a manual turret level correction.

(f) Eliminate the infinity ring sight and use the speed ring sight for sudden attacks at low altitudes where high speed optical acquisition is an absolute necessity, but where lead angles are small and tracer fire is adequate.

(g) Add IFF for use on distant targets picked up by the radar.

(h) Eliminate emergency operation on batteries for the self-propelled mount.

C. RADAR STUDIES

During the last quarter very little consideration has been given to the radar for the 37-mm Stinger because manpower has been concentrated on completion of the second caliber .60 Stinger.

However, some thought has been given to the redesign of the transmitter using the QK-305 or some similar high power magnetron. It is anticipated that a thorough study will be made of the KU band components which have been developed over the past few years, and that the r-f system will be redesigned to incorporate those components which are superior to the ones used in the present Stinger radar.

Some thought has also been given to the indicating system. The main question to be answered is whether or not stereo presentation will be used in the redesign. Investigations will commence shortly on this problem. Whether stereo is used or not, a different type cathode ray tube will be used. The present tube (3JP1) has shortcomings both as to persistence qualities and resolution.

D. COMPUTER STUDIES

The computer program is proceeding on the basis of three models which are distinguished by the amount of redesign involved. The design study of the Model 1 Computer is 90 percent complete. This project is presented in Section III, in which the layouts to be found in the rear of this report are described. The work specifically remaining on Model 1 consists of ballistics mechanism space studies, breadboard tests of the precession mechanism, and packaging studies of the tracking unit (main section). During the latter project some degree of simplification will be attempted and some changes in the radar indicators are anticipated. The TM computer tests for Model 1 as well as Model 2 will begin in January. The range servo tests will probably apply to all three computer models.

The Model 2 Computer study has been very active during the past quarter. In addition to a shorter rotating element, the design study of this model now includes a new type precession mechanism which promises a distinct accuracy improvement over Model 1. The new mechanism (called a precession torque multiplier) in effect divides the lead angle by modified time of flight. The two precession servos are superseded by two RF (or 1/TM) servos. The mechanism, described in Section III, paragraph I, will be built shortly for breadboard tests. As presently visualized, the Model 2 Computer will also be considerably simpler than the Model 1. Packaging and data flow studies are in progress which will reduce the number of cams and eliminate much of the gearing in the tracking unit. (See Section III, paragraph B.)

The Model 3 Computer studies are expected to begin during the next quarter. It is possible that an approximate solution will be the basis of this study which may permit drastic simplification compared to Model 1. This program cannot begin until the course calculations are complete as these will determine the mechanization as well as the feasibility of the approximations.

The accuracy study has begun; the target course calculations being the first step. This data, when complete, will:

(a) Furnish TM values which can be used to study approximate solutions (Model 3).

(b) Make possible a balanced study of accuracy requirements based upon tactical frequency and hit probability.

(c) Facilitate a realistic determination of specifications (L max, PR max, TM max, etc.) or military characteristics.

A more detailed outline of this program is provided in Section III, paragraph L.

In the first quarterly report two TM computer designs were discussed, one for the Model 1 Computer and the other for the Model 2 Computer. This concept has been changed. The Model 1 Computer is now to have a TM computer with PR servos where the Model 2 Computer will have RF servos. Other methods for calculating TM will probably apply equally to either computer and will be indicated by suffixes A and B applied to the TM computer models. The A model will solve for SCRF by splitting it into VCRF and RCRF. The Model B will solve for SCRF electronically in one step. The following table shows the differences between models of TM computers. Any characteristics not listed are the same as for Computer T26.

TABLE 1-1

DIFFERENCES IN MODELS OF THE TM COMPUTER

	Model 1A	Model 1B	Model 2A	Model 2B
Auto Balancing (VT and RF) (for PR servos only)	X	X		
LRF & VRF circuits			X	X
RCRF circuit	X		X	
VCRF circuit	X		X	
Electronic SCRF		X		X

All of these models will have a BCV isolation amplifier added and possibly an automatic compensator for changes in gyro speed. The latter feature would eliminate the need for a precise power supply.

Progress Report No. 1 mentioned two programs for the improvement of the isolation amplifier. One involved 2-1/2 tubes and the other, four tubes. It has been found that a special transformer would be prohibitive in size, and any other approach would require extensive development. It is not yet evident that isolation amplifier improvement will be essential for the 37-mm computer, however. Greater detail on this program will be found in Section III, paragraph J.

In connection with the parameter or limit study, considerable progress has been made. The TM computer settling requirements have been analyzed and all of its limits established, pending results of the accuracy and probability study. The analysis and its tabulated results are to be found in Section III paragraph M. Limits of L max, PR max, $P\dot{R}$ max and $P\ddot{R}$ max remain to be fixed by the probability study and the ballistic effects limits will be determined under ballistics studies.

Also included in Section III is a report on potentiometer investigations. It has been found possible to order Helipots with double wipers and tight specifications on resolution and backlash. The report also describes two potentiometer life and servo tests which are soon to be made. Both programs involve the comparison of several designs and specifically aim to evaluate slide wire potentiometers made by G. M. Giannini and Co.

E. TURRET AND VEHICLE STUDIES

During the past quarter additional design work has been done on the mounting and equilibration of the guns and on the storage and feeding ammunition. A brief listing of the present state of these studies follows. Further discussion will be found in Section V.

(a) Ammunition will be hung in a vertical column from two simple racks, and be pulled from the racks by boosters. The boosters will deliver the rounds into external flexible chutes for supply to the guns.

(b) It is proposed that an extension to the receiver on the Armour gun (T172) be made so that the gun may be bolted to the turret trunnion.

(c) The Dixon gun (T37) will be mounted in a cradle which in turn will be bolted to the turret trunnion.

Design work started and carried out during this quarter included work on the azimuth power control package, an examination of clearances and supports in the vehicle, a study of the construction of the upper and lower structures, and work on the main azimuth bearing with a view to the adequate distribution of firing loads to the balls.

Engineering work on this subject also included three extensive computations which will be of assistance in the turret servo analysis. The first was the approximation of a sample gun reaction-time diagram by a Fourier sine-cosine series of the form

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \sin n\,\omega t + \sum_{n=1}^{\infty} b_n \cos n\,\omega t$$

The coefficients a_o, a_n, and b_n for the first seven harmonics were determined. The second concerned the determination of the spring constant for the azimuth power gear box. The third was a computation of the rotational moment of inertia of the turret about its azimuth axis and of the guns about the elevation axis. Additional engineering work was concerned with the distribution of firing loads into the main azimuth bearing and with ammunition booster performance.

A reexamination of the primary electrical power supply for Stinger was begun with a view to the possible substitution of a 400-cycle, three-phase, 115-volt supply for the 28 volt d.c. supply presently used.

SECTION II

TRIPS AND VISITS

Mr. T. Williams visited Watertown Arsenal to discuss the feasibility of helical gun equilibrator springs. In spite of the experience with this type of spring on Skysweeper, it is felt that with care a satisfactory helical spring can be made. Extreme fibre stresses of 155,000 to 190,000 pounds per square inch have been used in the past although some breakage has been experienced. For Stinger service a stress of 125,000 pounds per square inch was agreed on.

Mr. T. S. Williams visited Detroit Arsenal to discuss the adaptation of the Gun, Twin 40-mm self-propelled, T141 to accept the Stinger turret.

Mr. T. S. Williams visited Armour to confer with them on mounting of the Armour gun and to keep up to date on the design work on their gun. They are considering shortening the belt pitch to 2.86 inches and designing a push-thru type link.

Mr. T. S. Williams visited Dixon Research together with Mr. S. Rosenblum of Armour Institute to discuss a proposed push-thru type link.

Messrs. T. S. Williams, W. Drewes and F. J. Hoffman visited Vickers, Inc., Detroit, Michigan, to discuss design techniques for the power controls on Stinger. Topics discussed included relief valves, pipe length, oil coolers, stroking system, pilot valve, and details of construction of the proposed hydraulic breadboard. There was some discussion regarding the possibility of using an hydraulic ram to drive the guns in elevation and on constant speed hydraulic drives for alternating current generators.

Mr. C. M. Jansky visited Raytheon Manufacturing Co. to observe operation of a type QK-357 recording tube and to discuss a direct view storage tube based on the same principle which might be suitable for presentation of Stinger radar information. Such a tube would store information and present it, as needed by the turret operator for acquisition, for longer periods than possible with the present long persistence tubes.

SECTION III

COMPUTER STUDIES

A. MAIN SECTION, MODEL 1 COMPUTER

During the last quarter, study of the Model 1 Computer was confined to the precession mechanism. Stadiametric ranging is strictly an emergency mode of doubtful value, and its elimination will make it possible to remove the range servo from the computer main section. Therefore, the range servo design study has become part of the study for the ballistic mechanism for the Model 1 Computer. The precession mechanism progress for Model 1 is discussed in paragraph G of this section.

B. MAIN SECTION, MODEL 2 COMPUTER

During the past quarter, work was begun on the general configuration, block diagrams, mechanization, and goals of simplification of the main section for the Model 2 Computer.

1. Cams Required

At present it appears that three cams will be used in the Model 2 Computer compared with the seven used on Computer T26. Two cams will be needed for the scanner drive and part of their output may be used for the combining glass. The cos L function is at present derived from a cam. Though other possible alternatives exist, a cam is possibly the best method of deriving cos L to .001 which may be the accuracy required. Cams used to obtain LPL, VPL, LS and VS may be eliminated as described in paragraphs 2 and 3 below.

2. Lead Input of Precession Torque Multiplier

In an attempt at simplification it is felt that the number of cams can be reduced without loss of accuracy. A reduction of 2 cams would be accomplished by deriving the LPL and VPL cam signals as follows

VPL and LPL are multiplied by RF to obtain VPR and LPR which torque the gyro.

$$\mathrm{VPL} \cdot \mathrm{RF} = \mathrm{VPR}$$

$$\mathrm{LPL} \cdot \mathrm{RF} = \mathrm{LPR}$$

$$\mathrm{VPL} = \frac{\sin L}{\sin LG} \sin VLG$$

$$\mathrm{LPL} = \frac{\sin L}{\sin LG} \cos LG \sin LLG$$

The lead input of the precession torque multiplier has an inherent sine function enabling the insertion of VLG and LLG directly while correcting RF for the difference between VPL and sin VLG as well as between LPL and sin LLG. Below is the actual mechanization in which the rate is a product of Lead input times RF input.

$$PR = (\text{Lead input}; (\text{RF input})$$

$$VPR = (\sin VLG)\left[\frac{\sin L}{\sin LG} \cdot RF\right]$$

$$LPR = (\sin LLG)\left[\frac{\sin L}{\sin LG} \cdot \cos LG \cdot RF\right]$$

The functions $(\frac{\sin L}{\sin LG})$ and $(\frac{\sin L}{\sin LG} \cdot \cos LG)$ vary no more than 5 percent and 2.5 percent respectively throughout the entire range of LG. Due to the small variation in these functions they should be simple to mechanize. The means by which they are multiplied by RF will be studied in the next quarter. The RF input of the precession torque multiplier will be called VRF and LRF for the respective units.

3. LS and VS drive

To attain in part the objectives described in the first quarterly progress report for the Model 2 Computer study namely, width reduction, increased accuracy, and simplification of the computer - and the simpler objectives described for the Model 1 Computer study, an engineering investigation of the combining glass drive was initiated.

Initially, work was concentrated on a quantitative analysis of the LSM and VSM functions inscribed on the cams driving the combining glass. It was found that the LSM function could be approximated by a function of LLG and LLC, and that the VSM function could be approximated by a function of VLG and VLC. Thus, it appears feasible at this time to eliminate the LSM and VSM cams from the computer without significant loss of accuracy.

It was further noted that with a small loss of accuracy, VSM could be approximated as a function of VLG only. Thus, if this approximation were acceptable, it would eliminate the need for a mechanical differential required for the summation of the VLG and VLC functions as considered above. It further suggests the possibility that a change in the gimballing of the combining glass may permit the introduction of the lateral component of aided laying directly between the gyro and the search prism. This would then reduce the motion of the combining glass to motion about one axis only. Mechanization of the combining glass would be greatly simplified, and greater accuracy could be expected from the mechanical simplification.

Yet, because of the attendant high shaft values associated with the combining glass, it is planned to initiate a comprehensive study to determine the most desirable method of displacing the reticle. In addition to the possible solutions described in the preceding paragraphs, the use of an illuminated cross hair to be displaced in a focal plane, either directly beyond the search prism, or in the internal optics assembly will be investigated. The question as to whether the components of cross-hair motion in the focal plane can be made a function of the already existing shaft drives will have to be investigated.

4. VB Mechanization

It is hoped that the VB servo can be eliminated and that VBL can be introduced as a correction of torque in a manner similar to LBL. VBL for the 37-mm Stinger will be of greater magnitude than for the present .60 caliber Stinger due to the increased time of flight which allows for a greater gravity drop of the projectile. This greater magnitude of VBL will require greater emphasis on its accuracy.

If VBL can be introduced as a precession rate correction called VBPR, the PE servo will become an FE servo and will position the FE synchros directly. In Computer T26, FE is derived by adding PE and VB, each from individual servos, through a mechanical differential. Also,

$$SE = FE - TVL$$

where

$$TVL = VL + VBL = VL + \frac{VBPR}{RF}$$

formerly

$$SZ = PE - VL$$

The investigation of this mechanization has yet to be made.

5. QE Mechanization (For Ballistic Corrections, Only)

With the existence of an FE servo, a more exact solution for QE may result, for in the Computer T26 QE is approximated by making it a function of PE plus tilt. This mechanization requires a QE servo, for tilt is an electrical signal coming from the inclinometers, which must be added to PE. Actually, QE should be a function of FE plus tilt which will be simpler to mechanize, for an FE servo now exists. Also, if tilt existed as a mechanical motion QE could be obtained by adding FE and tilt with a mechanical differential. Such an arrangement will be studied.

A study will be made to determine the feasibility of using only FE to represent QE, this being a means of simplification. The magnitude of the error of such an approximation and the probability of large tilt angles will govern its feasibility.

Another arrangement would insert tilt as a separate ballistic correction without adding it to PE to obtain QE. This could be done electrically without the need of a servo gear train.

6. Location and Packaging of TF and DO Servos

The possible elimination of stadiametric ranging as a required mode of ranging for the 37-mm Stinger would eliminate the necessity of locating the range servo inside the computer main section. Thus, in line with the planned engineering and design studies to be made on the range servo itself, the opportunity presents itself to make a thorough packaging study of the TF and DO servos.

The primary functions of the time of flight and range servos are the determination of the response factor of the sensitivity computer. The two servos are functionally complimentary and are similar. Thus, it would seem logical that they should be made physically adjacent. The probable elimination of the QE servo from the 37-mm Stinger would offer the opportunity of inserting the DO servo in the ballistic mechanism assembly, located in the lower structure.

Inserting the range servo in the ballistic mechanism seems to offer the following advantages.

(a) Fewer leads are required to the computer main section.

(b) Because of the proximity of the computer servo and isolation amplifiers to the ballistic unit, shorter leads between the range servo and related chassis may be used..

(c) Elimination of some extraneous sources of heat from the computer main section can be accomplished.

(d) Additional space will be available in the computer main section.

(e) Greater concentration of the components of the TM computer is possible.

Consideration should be given to locating all secondary ballistic inputs, excepting perhaps wind correction, along the left-hand cockpit wall, where the relative air density input and dial assembly are now located.

Yet before any final decision can be reached, consideration will have to be given to overall wiring and packaging of Stinger components in order to insure maximum economy of design.

7. Packaging and Data Flow

If the previously mentioned changes are made, an overall simplification of the computer packaging appears possible.

The six synchros (fine and coarse for TLL, SE and FE) on the left hand dial panel in the Computer T26 will be relocated to lie with the main computer gearing under the rotating element. Such an arrangement will increase accuracy and reduce backlash by eliminating long gear trains and complicated bevel gear drives to the dial panel. The dials on the left hand dial panel which are driven by these gear trains will also be moved under the rotating element. They will be visible for test purposes from the front of the computer.

The data flow of the proposed computer is shown in block diagram form in figure 3-1. There are three cams, a reticle drive, a rotating element and five mechanical differentials in this arrangement.

The reticle drive shown in the figure is not the simplest but it is one which is feasible. The vertical drive of the reticle is by VLG alone while the lateral drive is a function of LLC from the cam unit with an additional correction made by providing a pulley ratio other than two to one between the search prism and the gyro. Other possible arrangements will be studied.

The LLC and VLC cams are a means of obtaining the TLL and TVL motion with the greatest accuracy. The LLC and VLC data actually corrects for the difference between TLL and K_1LLG and between TVL and K_2VLG respectively. TLL is mechanized by adding K_1LLG and LLC through a mechanical differential. A differential has been eliminated by obtaining SE from the subtraction of VLC from GYE instead of the method used in the Computer T26 where K_2VLG would be added to VLC to obtain TVL which would in turn be subtracted from FE. The addition of LLC and GYE gives SE as follows: (assuming VBL = 0, so that TVL = VL + VBL = VL)

$$TVL = K_2 VLG + VLC$$

and

$$SE = FE - TVL$$

$$GYE = FE - VLG$$

therefore

$$SE = GYE - VLC \text{ where } K_2 = 1$$

The possibility of using the new VSM (= K_3 VLG) instead of VLC in this equation, or vice versa, will be investigated shortly.

The differential adding LLG to GYE nullifies the trunnion effect occurring while transferring LLG to the rotating element. LLG on the rotating element displaces the lateral pickoff coils and is the lead input to the lateral precession torque multiplier.

Two trunnion effects must be corrected to obtain VLG in the vertical precession torque multiplier. These trunnion effects subtract GYE and LLG, but by adding FE and LLG with one differential, VLG will be computed.

$$FE + LLG - GYE - LLG = VLG$$

8. Computer Narrowing Program

The latest engineering and design studies of the mounting of the 37-mm gun on the upper structure seem to indicate that interference between the guns and the computer will be restricted to possible contact between the gun barrels and the Winchester plug boxes of the computer only. Thus, at this time, since the plug boxes can be redesigned and relocated without great difficulty, no necessity exists to reduce computer width.

However, until final mounting of 37-mm guns is approved, the study of possible reduction in computer width will be pursued. Reduction of computer width would eliminate all interference between the guns and the computer plug boxes, increase clearance between the barrels and the computer cover, and decrease physical size of the computer.

9. Prospective Indicator Tube Changes

Some amount of redesign is planned for the indicating system. As indicated previously, little consideration has been given to the problem during the past quarter because of the work being done on the caliber .60 Stinger. It seems probable that with further investigation a larger system of presentation will be recommended.

Use of two indicator tubes, with 3-inch diameter tube faces as at present, but with greater persistence and resolution, coupled with increased magnification of the optics, will necessitate redesign of the computer indicator opticals.

Use of two indicator tubes, with 6-inch diameter tube faces to increase the presentation, offers another possible solution. Because of the major repackaging and redesign studies being undertaken on the computer main section, the 6-inch tube face diameter dimension does not appear to offer insurmountable difficulties. However, if the increase in tube face diameter is accompanied by increase in tube length, it may prove impossible to maintain the tubes in their present location without increasing the width of the computer. Since it is desirable to decrease the width of the computer it may be necessary to relocate the indicator tube assemblies. This would necessitate considerable redesign of the optics.

If stereo presentation is no longer required, radar presentation might be envisioned through only one 6-inch diameter tube. This would eliminate any serious packaging difficulties. The external optics might need to be relocated somewhat to compensate for possible increase in tube length. However, these modifications appear to be of minor importance. Further, use of only one indicator for the radar presentation may permit simplification of the external optics, which requires two head positions on the computer T26.

C. ROTATING ELEMENT, MODEL 2 COMPUTER

Redesign of the rotating element is necessary because of the expected need for narrowing the computer main section to make room for the 37-mm guns. A study was made of the feasibility of shortening the rotating element to accomplish this. The results were reported in Quarterly Progress Report No. 1. Since no further changes have arisen in the Model 2 rotating element length, this project is closed.

D. MAIN SECTION, MODEL 3 COMPUTER

The study of the Model 3 Computer has not progressed far enough to produce any schematics. It is expected that design studies will begin during next quarter.

E. BALLISTIC MECHANISM

The design studies of the ballistic mechanism for Model 1 and 2 Computers are scheduled for March 1953 and for the Model 3 Computer in May 1953. They will follow the ballistic studies which are presently being deferred because of conflicting work on Director T42. The ballistic studies will determine how the corrections to basic projectile velocity are to be mechanized, together with the wind and gravity deflections.

F. PRECESSION MECHANISM MODEL 2 AND 3 COMPUTERS

The precession mechanism study is the most important project in the computer study. It has changed its direction considerably since the previous progress report, because a new principle was discovered for applying torque to the gyroscope. The non-linear approach and the coarse and fine approach have been dropped from the study program and the servo aspect of the project has been greatly eased.

The error in the T26 precession mechanism was largely one of data transmission, as explained in the previous progress report. The problem of establishing precession rate to an accuracy of one part in 21,600* was formidable from the mechanical viewpoint even if a slide wire potentiometer and an unusually tight servo were to be utilized. AS explained in paragraph I of this section, the mechanical and servo accuracy requirement is relaxed by ten to one when the data transmitted becomes RF (reciprocal of modified time of flight) instead of precession rate, PR. The precession rate is now established by a linkage which multiplies RF as a force by a lever arm, to produce a torque on the gyroscope. The lever arm is made to vary in effect proportionally to sin L. Since the maximum rate of ±1600 mils per second will now be produced by varying two motions (PR and sin L) instead of PR alone, all resolution problems are relieved. Another advantage of the precession torque multiplier is that the RF voltage is always positive. Consequently, no amplifier is required to maintain two balanced RF voltages. Neither is a balanced ±VT required for servo feedback potentiometer excitation.

$$*21{,}600 = \frac{2\ \mathrm{PR\ max} \times \mathrm{TM\ max} \times \mathrm{DP\ max} \times 10^{-3}}{E_n} = \frac{3200 \times 15 \times 4.5}{10}$$

Considerable study was devoted during the past quarter to the problem of producing a varying force proportional to RP. The most straightforward approach would seem to be the mounting of a solenoid of a magnetic torquer on the-lead plate. Such torquing methods are widely used on other gyro angular rate computers and are highly developed. It was found, however, that the Stinger PR max and gyro angular momentum are so high as to require the torque to be amplified roughly 16 times, while the large pickoff error (±6 degrees) would cause the armature displacement far beyond the operating limits of the torquer. Because of the wide use of magnetic torquing techniques in other gyro computers, the feasibility of adapting them to Stinger was studied at great length. It was concluded that these techniques are adaptable to Stinger.

Many arrangements of linkages were studied, with the object of cancelling out the armature displacement resulting from pickoff errors. This proved impossible without cancelling out the torque as well as the displacement, however. One solution to the magnetic torque approach was conceived, as shown by figure 3-2. In this system, a servo is provided to wipe out any displacement by moving the magnet stator before such displacements become large. In comparing this arrangement with that of the precession torque multiplier, no advantage is apparent other than a slight improvement in mechanical simplicity. Even this conclusion is questionable until a design study is made. More significantly, there is the bulk of the electromagnet or torquer, which might add 30 percent to the volume of each precession mechanism. In addition to having a servo for each axis and an added pickoff, extra electronics will be required to power the torquer and to provide constant current excitation. If pursued further, the electromagnetic approach would also require extensive laboratory research.

Although it probably is feasible, this method was abandoned without further investigation of the problems of torquer linearity, inertia (with respect to gyro nutation), electronic design, or mechanical design. It was not expected that linearily would be too serious a problem, because it was not a matter of resolution. However, some components did not look too promising in this respect. New a-c components are now under development by Midwestern Geophysical Laboratory comparable to their No. 9 Torque Motor. If in a few years they can approach the torque and linearity requirements desired for the precession torque multiplier, electromagnetic torquing might become simple enough to consider.

The decision against generating the force magnetically was made largely because it would be more complex with present day components than to use a servo for creating a spring force proportional to RF. Therefore, the present program has been restricted to the latter method, as described in more detail in paragraph I of this section.

Referring to paragraph I and to figure 3-3, it will be seen how the precession torque multiplier has been designed for laboratory breadboard. An RF servo has effectively been mounted on the lead plate, in place of the electromagnet or torquer originally contemplated. In order to meet space limitations, the RF servo motor is actually external to the lead plate, and drives the linkage and potentiometer through its trunnion. Instead of actually displacing the precession spring in proportion to RF, the varying RF force is produced by changing the angle of the spring force vector. A further refinement is described whereby parts of the gimbal corrections are combined with the two RF servo inputs. As a result the lateral RF servo is called LRF and the vertical servo is VRF.

G. PRECESSION MECHANISM, MODEL 1 COMPUTER

A design study of the precession unit for Model 1 Computer was completed eary in the quarter. Main objectives for this study were greater potentiometer accuracy, improved mechanical accuracy, and refined adjustment provisions. The ten-turn SAN 33B Helipot mentioned in the previous quarterly report is no longer contemplated for Model 1, because of its roller wiper. A complete discussion of the potentiometer situation is to be found in paragraph H of this section. The design studies made, were strictly from the space viewpoint with regard to potentiometers. It has been proven feasible to mount ten-turn potentiometers in the units, without increasing the dimensions of the rotating element. The dimensions for these components were based upon those of Helipot type AN ball bearing 0.02 percent units, although the multi-turn potentiometer market is quite fluid at present. The final recommendation of this study might be for a slide wire potentiometer, a dual finite resolution potentiometer, a composition potentiometer, or a multi-turn unit made by one of the newer vendors. Figures 3-4 and 3-5 show a design involving a ten-turn Helipot. A twenty-turn unit appears mounted on its side (parallel to the gyro spin axis) in figure 3-6. In the LPR mechanism, it has been shown in a vertical position in figure 3-7 and 3-8. Another layout, figure 3-9 proved that the potentiometer was too long to be mounted vertically in the VPR servo. In each case the gearing has been altered for the new shaft values. The motor ratios have been improved by about two to one in terms of mils per second per revolution but could not be improved greatly with respect to the potentiometer. The latter ratios are:

T26 computer: 7.8 to 1

Ten-turn Helipot: 8.27 to 1

Twenty-turn Helipot: 4.17 to 1

The design work has been halted indefinitely until the servo studies analyze the requirements as to motor size, friction errors, inertia, maximum rates ($\dot{P}R$ max) and maximum accelerations ($\ddot{P}R$ max). The potentiometer life tests and servo tests will also produce a decision as to which layout will be proposed, and will help to specify the potentiometer more exactly.

Figures 3-7 and 3-8 indicate that a twenty-turn finite resolution potentiometer is too long to be mounted for proper access without extensive redesign of the rotating element castings. It is not certain whether Model 1 should permit that much change in the Computer T26 design. However, a twenty-turn slide wire potentiometer (if proven feasible) would be about the same length as a ten-turn Helipot, and could be inserted in any of the twenty-turn potentiometer layouts made so far.

In all of these Model 1 precession mechanism layouts great attention was given to mechanical precision between the potentiometer and the torque rack. In anticipating improvements along these lines, however, figures 3-6, 3-7, 3-8 and 3-9 included studies of a worm or screw drive for the rack. A test program is contemplated to determine the feasibility of this approach. Further study is also planned as to various methods of backlash elimination. The tests will investigate the servo problems, comparing the friction and inertia of the worm drive with conventional spur gearing. Such a program cannot be planned until the outcome of the potentiometer tests is known.

Figure 3-10 shows a design for improving the adjustment of zero rate when the lead is zero. This is known as the "creep" adjustment, and consists mechanically of displacing the potentiometer with respect to the torque plate. In the layout this adjustment is provided by loosening two locking screws and moving the scotch yoke relative to the torque rack.

H. POTENTIOMETER STUDIES

During the past quarter, the potentiometer problem has been studied with less emphasis upon the precession servo and more upon the range servo and the new RP servo, for Model 2 Computer. It was mentioned in the preceding report that two slide wire potentiometers were under consideration: a Sperry made unit and a unit to be purchased from G. M. Giannini and Co. The former layout was completed and rejected on the basis of excessive inertia. On the other hand, some units manufactured by Giannini have been received in values of 1000 and 2000 ohms. In the ten-turn model, 2500 ohms is considered the maximum practicable resistance value. It has been learned that a slide wire unit is under development by the Helipot Corporation.

A 1000 ohm ten-turn slide wire potentiometer is shown in figure 3-11. This shows the continuous wire used to produce infinite resolution, simulating conventional potentiometer with an infinite number of windings. For comparison a three-turn conventional Helipot has been illustrated in figure 3-12. This pictures the internal construction of the units used in the T26 precession servo. During the past quarter it has been revealed that the Giannini slide wire design produces a linearity of 0.05 percent, and 0.02 percent is promised in the near future. The Giannini component is being considered, especially for the Model 1 precession servo and the Model 2 RF servo. It cannot be contemplated for the range servo feedback position, however, because resistance is too low.

In order to determine the feasibility of the slide wire potentiometer, a critical life test is to be conducted shortly. This test will compare multi-turn potentiometers manufactured by Giannini, Helipot, Rattray, and Electromath. All of these units except the first are finite resolution designs, and one Helipot is to be tested which has a roller wiper. The tests are to emphasize the effects of servo oscillation upon noise, linearity, backlash, loose windings, etc. In addition to determining failure due to wear, the slide wire units will be evaluated on the basis of wire stretching and shorting. After completion of this preliminary test, plans will be made for environmental tests such as humidity, temperature, vibration, etc.

While awaiting the results of the potentiometer life tests, potentiometers are being ordered for the servo tests in this contract. On the assumption that some defect will appear in the slide wire design, an attempt is being made to maximize the suitability of finite resolution potentiometers for servo applications. Ten-turn ball bearing Helipots have been ordered with double tandem wipers for test in the range servo, the precession servo (Model 1) and the response factor servo. In order to study the relationship between potentiometer imperfections and servo troubles, these Helipots have been ordered with "precise regions" of 0.02 percent linearity, specifying no shorted windings or loose windings. Backlash has been limited to 0.01 percent, and a method has been developed for measuring it. No roller wiper units have been ordered because it has been reported that they wear eccentrically, so as to develop a bouncing action eventually.

If the slide wire potentiometer proves to be of doubtful feasibility, it is probable that the breadboard servo tests will include investigations of the effects of the following:

(a) Sleeve bearing Helipot
(b) Dual ball bearing Helipots in parallel
(c) Double wiper ball bearing Helipot
(d) High-resolution (16000 turns) Helipots
(e) Precise Region versus normal region (comparing the single dual and double wiper arrangements)
(f) Effects of reduced wiper tension on dual and double wiper units
(g) Effects of optimum spacing between double wipers
(h) Composition slide wire potentiometers (Micromax)

It was originally intended to conduct range servo breadboard tests as well as servo tests of the precession mechanism. In the case of the Model 2 Computer, the precession servo tests will become RF servo tests (distinct

The potentiometer and gear train in the above system would have to measure PR to an accuracy of 0.11 mil per second (mps) at low rates. As discussed in the previous quarterly report, this accuracy would be difficult to achieve with the above mechanism.

The new mechanism will be termed a precession torque multiplier. It differs from the existing mechanism in that the tension in the arm varies. This allows the mechanism to have two inputs which are multiplied together, namely Lead x RF = PR*. Such a system has no gear train or potentiometer as a function of PR and, therefore, is not concerned with the accuracy requirements of PR. (See figure 3-14.)

The introduction of RF is the major problem of the precession torque multiplier. It appears that RF must be measured to at least one part in three thousand, as is shown below.

The travel of RF is for the present design 4 $\sec^{-1}$ to $\frac{1}{18}$ $\sec^{-1}$,

therefore

$$ERF (\frac{1}{3000} \times 4 = .001\,3 \sec^{-1}$$

---

* The actual equation mechanized is:

$$Lead \times RF \times AM = TG = AM \cdot PR$$

where TG is the torque at the gyroscope, and
AM = the (constant) angular momentum of the gyroscope.

Maximum error will occur for a 2000 yd. RC, 400 yps TV target when $RF = \frac{1}{14}\ sec^{-1}$ or TM = 14 sec. This occurs when opening fire (DP ≈ 4500 yds). The associated precession rate occurring for such a target is about 13.3 mils per second.

Now $$(Lead) \cdot (RF) = PR$$

and to find the value of Lead for an error of RF of .0013 sec^{-1} at a PR of 13.3 mils per second we can say

$$E_L = E\ Lead = \frac{(PR)}{RF} - \frac{(PR)}{RF + ERF}$$

$$E_L = \frac{13.3}{\left[\frac{1}{14}\right]} - \frac{13.3}{\left[\frac{1}{14} + .0013\right]}$$

$$E_L = 186.2 - 182.9 = 3.3 \text{ mils}$$

An E_L of 3.3 mils at 4500 yds. DP corresponds to a 14.8 yard E_N (error normal to the trajectory). This 14.8 yard error illustrates why an upper limit for RF must be very conservatively chosen. (See Section IV.) If RF maximum can be reduced from 4 to 2 as a result of the probability studies, this E_N will be cut in half as a result of reduction in E_{RF}. Moreover, 14.8 yards mean point of error may prove compatible with the system dispersion at 4500 yards. If neither of these conclusions is reached, however, there is some prospect for obtaining one part in 6000 RF servo accuracy through use of a ten-turn helipot or a slide wire potentiometer. This subject has been discussed in paragraph H of this section.

Lead will be introduced from the existing deflection gear train (LLG and VLG) and will position the arm rotating about point P. This arm may be positioned in figure 3-14 with the same accuracy as in figure 3-13. From available data taken on the T26 precession mechanism it is known that the arm in tension can be positioned to better than 1/3 mil of arc. The arm can rotate through 1060 mils (60°). Therefore, the arm can be positioned to one part in 3000 or Lead is introduced with an accuracy of $\left[\frac{1}{3000}\right](\pm 540 \text{ mil}) = \frac{1}{3}$ mil or 1.5 yards at 4500 yards.

At present the means of introducing RF is by an RF Servo which rotates a spring in constant tension, thereby changing the tension on the arm applying torque to the gyro. A more detailed explanation follows in which the precession torque multiplier is designed for minimum variations of torque output with pickoff error.

The proposed precession torque multiplier is basically the spring torque mechanism used in Computer T26, to which the means to introduce another coordinate of data has been added.

Both mechanisms feature the use of springs under essentially constant tension; both mechanisms feature variation of the torque applied to the gimbal arm by variation of the angle through which the spring tension acts. But while in the Computer T26, the magnitude of the effective lever arm is a function of but one mechanical input (precession rate), the magnitude of the effective lever arm in the precession torque multiplier is the resultant multiplication of two separate mechanical inputs, lead and response factor.

The proposed arrangement is shown in figure 3-15. The exact mechanization can be made in the final design. As can be seen, the torque on the gimbal arm (GO) can be changed by varying the angle of the "lead" plate through motion of the rack X, and also by varying the "RF" plate (PF) through motion of the rack Y. Closer inspection of the proposed mechanism will show the need of coupling motion of the RF plate to the motion of the lead plate, so that motion of the pivot point B is not inherently accompanied by a variation in the torque applied about B by the spring CF.

In addition, the following considerations must be made in designing this linkage.

(a) Motion of the gimbal arm (GO) represents pickoff error. In order to maintain zero torque conditions for other than zero pickoff errors, it is required that axis A must pass through the centerline of axis G.

(b) To permit transfer of lead data about trunnion P through the "lead" plate to the torque arm CBA, axis O must pass through the centerline of trunnion P.

(c) To maintain constant spring tension, axis C must pass through the centerline of trunnion P.

(d) The line PD must not pass through the pivot point B so that it will be impossible to apply a compressive force on link arm OA. (Normally, this will not occur because RF is greater than zero.)

(e) The torque arm CBA must be balanced to prevent its rotation when the whole mechanism is subjected to shocks or forces caused by rotation of the turret.

The proposed arrangement introduces error through variation of spring tension when a pickoff error is in evidence. The torque required to attain the maximum precession rate now under consideration is 3.1345 inch pounds. The problem was to select a spring of such a magnitude and length as to minimize errors in torque due to the presence of pickoff errors and to minimize as well the spring extension required to attain maximum torque.

Initially, it was found that errors could be minimized by locating the pivot point B on a line at right angles to the torque arm position OA.

It was realized that maximum error would occur when full lead and full RF have been introduced in conjunction with a maximum pickoff error of ±6 degrees (i.e. the gimbal arm OG is caused to rotate through 6 degrees). A layout of the linkage under such conditions with AB = 1.00 inch is presented in figure 3-16. The result of this study indicated the most desirable spring rate as being 1.16 pounds per inch. In order to accommodate a spring with a 1.16 pounds per inch constant, it is necessary to introduce a toggle arm DFE (see figure 3-15 and 3-16) which pivots at F. The spring can then be halved and each half can be connected between P and E, and C and D. The percentage error in the gimbal torque under these conditions has been calculated to be 2.4 percent when the lead is in one direction and 1.2 percent when in the other direction. These errors may appear to be high, but when we consider that maximum lead and maximum RF are introduced with maximum pickoff these errors become negligible, and from all considerations this seems to be the best arrangement that can be desired.

The design of the vertical precession torque multiplier has been completed and is being detailed. (See figures 3-17 and 3-3.) This unit will allow for the direct introduction of

VLG as a lead input in that the lead plate is positioned through radial gearing instead of a rack, thereby giving the sine of VLG (as discussed in the elimination of the LPL and VPL cams). The RP servo has its potentiometer mounted on the lead plate eliminating the trunnion effect which would occur if the potentiometer was mounted off the lead plate. The motor is not mounted on the lead plate for spatial considerations. This unit will be built as a breadboard and will be tested to determine its accuracy. A torque measuring device will be built to measure the very small torque outputs of the precession torque multiplier.

J. TM COMPUTER STUDIES, MODEL 1 AND 2 COMPUTERS

1. General Status

The study program of the TM computer for the 37-mm Stinger calls for a laboratory construction and test of the various proposed models in order to determine the feasibility of their application. The first proposal under consideration is the Model A (see Section I paragraph D)sensitivity computer. Plans for the laboratory construction of a breadboard model of this sensitivity computer are now fully underway.

2. Laboratory Breadboard

It has been established that all laboratory tests on the TM Computer will be static measurements. This eliminates the requirement of a dynamic test cam unit containing three two-dimensional cams. It is expected that a full knowledge of the feasibility of the TM Computer can be determined from the knowledge of the static accuracy of the sensitivity computer together with the dynamic response of the contained servos.

The TM Computer functions to generate an RP signal to drive the gyro processing device and operates from two input signals; Do, obtained from the radar synchronizer in tracking and cos L, obtained from a cam in the computer proper.

For the purposes of a laboratory mock-up, both of these input signals will be generated statically in the input data chassis from Duodial calibrated linear Helipots. The RP output signal will be used to drive an RP positioning servo which will correspond to the RP servo proposed for the Model 2 precession torque multiplier. (See paragraph I of this section.) This differs from the Computer T26 where the RP signal is used to excite the LPL and VPL cam potentiometers which in turn drive the precession servos.

Since the gyro acts to integrate and smooth out any perturbations in the RF signal, it has been proposed that a true indication of the effect of RF on the Stinger system can only be obtained by integrating the output of the RF servo rather than by using the RF servo output directly to predict the feasibility of the proposed TM computer. It is conceivable then that a variable speed drive integrator will be required at the RF output to permit a valid interpretation of the RF data.

In order to give wider latitude to the static measurements on the TM computer which will be made in the laboratory, it is planned to measure the computer accuracy at several static points on a dynamic course. To achieve this, both the DO and TF tachometers will be driven independently by variable speed drives to provide typical values of DOR and TFR. For the purposes of these tests these tachometers will be mounted on the tachometer unit which will be totally independent of the corresponding DO and TF shaft motions.

In order to avoid the necessity of the BPV cam, driven by TF, the laboratory mock-up will compute the APV quantity directly from the analytical trajectory.

$$APV = MV \cdot \frac{1/a}{1/a + TF}$$

Where a = the retardation coefficient.

Only a resistor circuit with a Helipot driven TF will be required.

Thus, the laboratory breadboard will contain the following main units

(a) Input data chassis
(b) VT reference chassis (precise voltage supply)
(c) Computer isolation amplifier
(d) Computing servo amplifier
(e) DO servo unit (fig. 3-18)
(f) TF servo unit
(g) Tachometer unit
(h) Measuring servo amplifier
(i) RF servo unit
(j) Static measurement chassis

The following sub-chassis have been built to provide the electronics for the computer isolation amplifier and the two servo amplifiers.

(a) 8-Triple-input isolation amplifiers

(b) 4-Double-input isolation amplifiers

(c) 5-Servo preamplifiers

(d) 1-DO preamplifier

(e) 5-Servo power amplifiers

These electronic units should provide sufficient flexibility to readily permit mock-up of Model B and all subsequent models of sensitivity computers as well as the Model A now under consideration.

3. Test Plans

The feasibility tests on the sensitivity computer will consist of static measurements on typical dynamic courses and dynamic response tests on the DO and TF servos.

The static measurements on the TM computer will consist of output readings of the SRF, RCRF, VCRF, and RF signals for typical inputs of DO, cos L, DOR, and TFR. These measurements will presume an MV of 1000 yards per second and an RD of 100 percent. No laboratory work on secondary ballistic circuits is planned.

The dynamic tests on the DO and TF servos will consist of measured frequency response data of the two units. Further plans for these dynamic tests have not been formulated.

4. Auxiliary Programs

Several auxiliary investigations have been planned on various components of the sensitivity computer. Tests on the Kearfott tachometer are completed which established the gain of that unit. Temperature tests on the tachometer and the design of a temperature compensating device to stabilize its transfer functions will not be undertaken unless they are found necessary in the accuracy analysis.

Investigations to obtain an improved isolation amplifier unit have been started but it appears that a higher gain unit would require a high quality transformer of prohibitive size. The packaging of an isolation amplifier chassis of approximately twice the size of that used in the Computer T26 is not feasible in the limited space allowed and it appears unlikely that a very much better unit could be built in the space allocated.

5. Model B, Electronic SCRF

One further proposal will be investigated as part of this study program. A circuit has been suggested to compute electronically the SCRF signal from a knowledge of (APV·DO). This would vastly simplify the analogue solution of the ballistic equation

$$RF = \frac{APV}{DO} - AK\,\frac{p(APV \cdot DO)}{APV \cdot DO}$$

by solving for the second term in virtually one process. Assuming u = APV.DO, an all electronic servo has been conceived to yield p (u)/u as a function of u inputs. However, the analysis of this circuit and accuracy considerations of its solution are very involved. It is planned that a thorough investigation of this proposal will be undertaken as part of the study on the Model B Sensitivity Computer.

6. Time Scheduling

The laboratory construction of the electrical components and the engineering design of the mechanical servo units are underway at present. It is planned that the electrical component wiring will be completed by the end of December and the servo unit will be set up by the end of January.

The alignment and component tests and set up of the integrated sensitivity computer will probably run through the month of February and the static tests on the system will be run in March. This will be followed by the dynamic test of the servos in April, which will complete all laboratory tests on Model A.

The design of the Model B sensitivity computer and investigations into subsequent models will start toward the end of March and further required mock-ups in the laboratory will start in late April.

Auxiliary investigations which may be necessary will be fitted into the schedule whenever time permits but will be started not later than the beginning of April.

K. TM COMPUTER, MODEL 3 COMPUTER

Because of conflicting activities, there has been little progress on the Model 3 study. In addition to a new exact solution, this project now includes the study of approximate solutions. This will have for its purpose the simplification of the standard ballistic solution, without the accompanying significant loss of accuracy.

Initially, it is planned to direct the study toward a simplification of the modified time of flight solution. Approximate solutions which might be more simply mechanized than that now employed in the Stinger sensitivity computer will be investigated. Special effort will be devoted to possible elimination of the TF servo, and one or more isolation amplifiers.

To date, three solutions have been considered, with but a very limited degree of success. First, it may be possible to eliminate the TF servo by using the analytical trajectory discussed in paragraph M of this section. (Refer to equation 3-12.) Second, an approximation of the SCRF term may permit simplification of mechanization. Third, an approximate empirical formulation of RF may be used. An example of this type of solution follows.

$$\frac{1}{TM} = RF = A + \frac{B}{DO} + C \cdot DOR$$

WHERE
A = factor related to MV
B = constant
C = constant
RF = response factor
DO = present range
DOR = present range rate

For the Stinger dynamic tester course this equation yielded values of TM having a maximum error of .01 seconds. For purposes of mechanization, it was considered impractical as it featured the difference of the two large terms B/DO and C·DOR for the incoming leg of the course.

Until such time as the course calcuations are completed, and a preliminary accuracy analysis made, it has been decided to defer the study of approximate solutions in order to minimize time wasted in the derivation of solutions characterized by excessive error.

L. ACCURACY STUDIES

It has been decided to make a tactical study of the 37-mm Stinger in order to determine the accuracy requirements of the fire control system.

A number of representative target courses, of different target speeds, crossover ranges, and target altitudes, have been selected for analysis. The tactical probability of occurrence of each target course will be considered and, for each course, hit probabilities will be computed. Present and future position parameters will be calculated at selected intervals throughout each target course. Thus, it is hoped to base the maximum accuracy requirements for the 37-mm Stinger fire control upon a sound evaluation of the tactical probability of occurrence of various target courses, and the hit probability on a plane flying these courses. The hit probabilities will be based upon factors such as gun angular dispersion, gun APV dispersion, tracking wander and servo smoothing, and radar range errors.

This study will permit an engineering investigation into the mechanization of the Stinger Computer T26 as adapted in Model 1 to the 37-mm gun, in order to seek possible economy in use of electrical and mechanical components.

The study will also provide accuracy criteria for the design of a new sensitivity computer. It will provide a basis for servo and component redesign, and will establish a limitation upon the dynamic and static errors allowable in the TM computer. For example, it will establish the accuracy with which the tachometers must be compensated for temperature changes.

The accuracy requirements may be such as to permit simplification of mechanization of SCRF, by permitting usage of approximate mathematical expressions for that term in the RF solution and it will provide a sound basis for the study of approximate solutions for RF.

It will indicate the accuracies to which non-standard ballistic corrections must be computed and mechanized.

Thus, instead of solely extending the accuracy requirements of the caliber .60 Stinger fire control to the 37-mm gun, it is hoped that this study will provide a more realistic basis on which to base accuracy requirements for the 37-mm Stinger fire control.

M. PARAMETER (LIMIT) STUDY

1. General

As part of the fire control parameter limit study it was necessary to establish values affecting the TM computer. The parameters are listed in the first quarterly report on pages 42 and 43. Values for L, MVC, PR, WV, and T remain to be established in the ballistic and course studies.

2. Maximum Sensitivity Parameters

The sensitivity parameters are TM (=1/RF), DO and TF. Because of the increase in DP_{of} from 2000 yards (caliber .30) to 4500 yards (37-mm), the selection of DO max. was more critical for this weapon. During settling, the value of TM for the Models 1 and 2 TM computer is governed by DO max, as seen in equation 3-7.

Furthermore, the accuracy of TM computation depends upon the scale factors of the range servo, as governed by DO max if DO min is to be held fixed. The DO max determined in this study refers only to the range servo travel rather than the radar limit.

The limit on TM as defined by equation (3-7) affects not only the isolation amplifier sensitivity, but more significantly the settling time, as defined by

$$ST = 3\ (AK-KFS)\ TM$$

for 95 percent of the lead angle error to settle out.

Although the fast settling feature indicated by KFS in equation (3-1) will lessen the concern over minimizing ST, it is seen that ST will still increase with TM. In order to achieve greatest accuracy and minimize ST, therefore, a more conservative approach has been taken on selection of DO max than the policy used for Computer T26. The previous viewpoint specified that the range servo should begin following when acquisition for settling begins. For a 400 yards per second target speed this would require that DO max exceed

DO_{of} by ST x 400 yards, or about 2500 yards (based upon the new ST and TM derived from the larger DO max). Similarly, the TF servo travel would exceed TF_{of} enough to produce a sizable decrease in APV. Thus TM max would become even greater.

The validity of the policy used for Computer T26 was carefully reconsidered for extreme values of DO, where settling of cosine L is a negligible part of the solution:

$$STM = \frac{\cos L}{1/TF + DOR/DO} \qquad (3\text{-}2)$$

It was concluded that the only settling function in the high TM computation is the acceleration of the DO and TF tachometers which will require roughly .02 second. The transient in the lead angle due to the DO and TF servos accelerating, will be about 10 percent when TM jumps from point f to point b in figure 3-19. This may be smoothed by introducing SCRF gradually, through a delay circuit, to produce a curve like c instead of b. The delay circuit, if used, would be disconnected when the target-in-range relay picks up (DP = 4500).

It should be pointed out that the T26 arrangement would have resulted in curve a when the DO and TF servos are moving to the point of opening fire. Curve b is predicted by making BPV constant when DP exceeds 4500 yards.

After deciding that computer settling (i.e. lead angle computation or acquisition) could begin before the DO and TF servos begin following, the object was to select DO and TF upper limits which would be as low as acceptable. DO max was the more critical problem because ST max is determined by curve b or

$$\frac{1}{TM} = RF = SRF - SCRF \qquad (3\text{-}3)$$

$$\frac{1}{STM} = SRF = \frac{APV}{DO} \qquad (3\text{-}4)$$

$$TM = \frac{\dfrac{DO}{APV\ (const)}}{1 - SCRF \times \dfrac{DO}{APV}} \qquad (3\text{-}5)$$

SCRF is the smoothing correction to RF, and never exceeds .01 at the beginning of a course. Therefore, the numerator of equation (3-5) is predominant in controlling ST max. From equation (3-4) this numerator is defined as STM. Since APV is equal to BPV for standard ballistics and is to be constant before opening fire

$$ST\ max\ \alpha\ TM\ max \simeq STM\ max\ \alpha\ DO\ max \qquad (3\text{-}6)$$

Because SCRF is positive at the beginning of a course, TM STM from equation (3-5). Nevertheless, STM is still appreciable before the range servo starts following, at which time the DO and TF tachometers begin generating an SCRF. This point is indicated by g on figure 3-19. Prior to point g the TM curve is constant, equalling

$$STM = \frac{DO\ max}{BPV\ min} \qquad (3\text{-}7)$$

This determines the settling time which is always to be expected during synchronization and establishment of lead angle, whenever the target is acquired with adequate warning. Equation 3-7 is shown at points f and h in figure 3-19. The former value is for standard ballistics and the latter for maximum air density.

The benefit achieved by limiting APV min and DO max is illustrated by comparing curve f with curve e, which would have been obtained by using the same logic as was employed in the Computer T26 design.

On the basis of standard ballistics and a 400 yards per second target, DO max could have been set as low as 8100 yards. However, some consideration must be given to conditions of high air density and low muzzle velocity which call for greater values of DO max. Since DO_{of} and TM_{of} are both greatest for courses in which RC = 0 (head-on courses), the DO_{of} was computed from the following, in which DP = 4500 yards and TV = 400 yards per second.

$$DO = DP + TV \times TF \qquad (3\text{-}8)$$

TF was chosen at 9.35 seconds, corresponding to a DP of 4500 when RD = 120 percent. DO_{of} from equation (3-8) becomes 8240 yards. After estimating limit stop windup and a safety margin for potentiometer alignment, a number was chosen for the potentiometer full travel. To facilitate calculations a round number was selected, making the full travel 8500 yards. After deducting a typical value for windup, the upper free travel limit became 8287 yards. By using equation (3-8) again, the maximum TF_{of} for head-on 400 yards per second courses is found to be 9.47 seconds. This permits accurate engagement of such targets with maximum relative density (RD), or a muzzle velocity drop of 270 feet per second, but not both simultaneously. With a greater value of DO max it would be possible to engage them with greater drops in muzzle velocity, but STM at point h has already become 17.311 (by substituting DO = 8287 and TF = 9.47 into equation (3-7)). Moreover, TM max is in the region of 20 seconds, as computed by equation (3-5)* and illustrated as curve d in figure (3-19). This so far in excess of the 15.1 seconds TM_{of} for standards ballistics as to make further concessions to non-standard conditions unreasonable. Therefore, 8287 yards was established as the

---

* SCRF for a head-on course was computed from $SCRF = AK\ pAPV \cdot DO/APV \cdot DO$ from which, for an incoming target: (3-9)

$$SCRF = AK \cdot TV \cdot APV \left[(1/(DP \cdot APV + DP \cdot TV) - a/(APV^2 + TV \cdot MV)\right] \quad (3-10)$$

absolute maximum DO free travel which could be contemplated. Since the Model 2 computer now involves the use of a precession torque multiplier, it is also necessary to select a conservative value for RF min, establishing TM max at 18 seconds. If the electrical end of the RF potentiometer represents zero RF, the servo limit stop problem is unusually severe and the RF voltage sensitivity is as low as practicable. Therefore, 18 seconds must be considered the maximum TM compatible with a lower limit of 0.25. This lower limit will be discussed later.

With TM max established as 18 seconds, it is seen from the shaded area d of figure 3-19 that one second of accurate firing will be lost on the 20 second TM course. This is a situation which makes further increase in DO max fruitless.

3. Minimum Sensitivity Parameters

The lower free travel limit of the range servo in the Computer T26 was 150 yards. It is desired to maintain a DO min in the 37-mm version which is fairly close to 200 yards, but some compromise is to be expected because of the increase in limit stop shaft value (yards per revolution). Furthermore, the only DO min of any significance is the one which is within the travel limits of TF and RF (1/TM). Because RF max is practically proportional to $1/DO_{min}$, a change in DO min from 300 to 200 yards makes a 50 percent change in RF travel, affecting sensitivities and RF servo scale factors by the same proportion. Therefore, the selection of DO min must be a critical compromise between tactical and technical requirements.

Referring to equations (3-5) and (3-9) it will be found that STM is less than TM on the incoming leg of a course. SCRF changes from plus to minus after present position cross-over on a straight line course. Since STM passes through its minimum before this point, TM always exceeds STM. On this basis a computer need never have a limit for TM which is lower than its limit for STM. Therefore, using equation (3-4)

$$TM_{min} = STM_{min} = \frac{DO\ min}{APV} \qquad (3\text{-}11)$$

In these equations the value of APV is taken when STM = STM min, a condition which occurs very close to present position cross-over. The analytical trajectory indicates the variation of APV versus DP for automatic weapons.

$$APV = MV - a \cdot DP \qquad (3\text{-}12)$$

where a is called the retardation coefficient and

MV = 3000 fps.

Also, it is evident that:

$$DO_{min} = DP_{min} = RC \qquad (3\text{-}13)$$

Substituting equation (3-13) into (3-11)

$$STM_{min} = \frac{DP\ min}{APV} = \frac{APV\ max \times TF\ min}{APV} \qquad (3\text{-}14)$$

Since APV max and TF min correspond to the value of DP min, equation (3-12) shows that APV is less than APV max. Consequently, TF min will always be less than STM min and should be used as a goal for STM min. This fact is expressed by combining equations (3-11) and (3-14).

$$TM_{min} = TF_{min} \qquad (3\text{-}15)$$

From equations (3-13) and (3-14)

$$DO_{min} = APV\ max \times TF\ min \qquad (3\text{-}16)$$

Substituting equation (3-13) into equation (3-12) and equation (3-12) into equation (3-16):

$$DO\ min = (MV - a \cdot DO\ min) \times TF\ min \qquad (3\text{-}17)$$

assuming a = .0961 seconds $^{-1}$ for this shell

$$DO\ min = \frac{MV \cdot TF\ min}{1 + .0961\ TF\ min} \qquad (3\text{-}18)$$

If expressions (3-15) and (3-18) are used to select the DO and TM limits in terms of the TF limit, these conditions will also be best for courses in which RC is less than DO min. The TF servo will always hit its limit first, so that none of the other limits will affect military characteristics. On the receding leg this will be a disadvantage, but the incoming leg is far more important tactically.

The preceding discussion shows that the minimum values of TM and DO ideally should be selected after establishing TF min. It is unlikely that 37-mm shell T81 will incorporate any safety feature, so it is assumed to be armed as soon as it leaves the muzzle. Therefore, it is not possible to establish TF min on the basis of arming time or arming range. However, there is a practical consideration in that very probably RF max cannot exceed 4 in the new computer without adding an isolation amplifier to avoid saturation. This establishes TM min as 0.25 on the basis of simplicity. In the Model 2 Computer, this aggravates the scale factor of the RF servo pot, but TM min will be left at 0.25 until further RF servo tests are conducted, especially with slide wire potentiometers. This would set TF min at 0.25 by equation (3-15), whereas it was 0.125 for the Computer T26. By equation (3-18), DO min becomes 244 yards, so this becomes the objective for the range limit stop. By using the same DO limit stop as in the Computer T26, the lower free travel limit for DO can be made 213 yards. The TF limit stop would require modification to achieve the required value of 0.25 For breadboard purposes, without modification, it will be 0.27, but could be 0.20 on a production design.

Limit stop modifications to reduce overtravel are definitely contemplated for any prototype or production design because it is essential that one electrical and of each sensitivity potentiometer (DO, TF, RP) represent zero or greater. Since the mechanical stops of multi-turn potentiometers are very close to the electrical tap, the limit stop spring windups consume active resistance windings on the potentiometer and establish the free travel limit of the variable in question. In designing the 37-mm computer, either these windup travels will be reduced by using motor slip clutches, or else the ten-turn potentiometers will be purchased with taps at 1/4 revolution and 9-3/4 revolutions. In the second approach, the free travel limit will coincide with the electrical limit of the potentiometer.

In reducing the free travel limits of DO and TF below 244 yards and 0.25 seconds respectively, the computer effectiveness will be improved after crossover on courses for which TM min is less than 0.25. Before crossover and throughout all courses where TM min exceeds 0.25, however, the minimum DO for accurate computing must still be specified as 244 yards. This is the limit derived from equations (3-15) and (3-18), and is only one which will apply to extremely slow targets.

The distinction between these military characteristics and the assumed design limits is made in the table which concludes this section. These parameter limits may undergo change as a result of the course probability study.

4. Differential Ballistics Parameters

The differential ballistic parameters are relative density (RD), muzzle velocity (MV), wind velocity (WV), and temperature (T). The extent of these ballistic corrections to velocity (BCV) and of the angular deflections (LBL and VB) are still to be studied. In Computer T26 the RD effect upon APV was introduced by means of a three-dimensional cam. The MV correction (MVCV) was introduced differentially by a non-linear potentiometer circuit. On the assumption that this same arrangement would be used in the 37-mm adaptation, it was desired to compute travel limits for basic projectile velocity (BPV). This variable is standard projectile velocity corrected for TF and RD.

Expression (3-12) was compared with the ballistic tables for Shell T81 and on an average value of a established as .0961 (for QE = zero). Since a is known to be proportional to RD x 10^{-2}, the minimum value of APV at the time of opening fire could be computed.

From equation (3-12)

$$BPV = 1000 - .0961 \times RD \times 10^{-2}$$

RD max was assumed as 120 percent corresponding to the value used in Computer T26. Following the policy established above for limiting STM max it is assumed that the BPV cam levels off beyond TF_{of}, which is 9.35 seconds for 120 percent RD. Therefore, a DP of 4500 was substituted in equation (3-12) to give BPV min as 481.06 yards per second. Using the same policy for RD = 100, BPV_{of} becomes 567.55. So long as the present mechanization is retained, however, this latter figure is only significant in determining point f of figure 3-19.

Since MV changes will not be introduced in the BPV cam, BPV max automatically becomes the standard muzzle velocity or 1000 yards per second. In comparing the new BPV limits with the figures of 486 and 1180 for Computer T26, there has been a 25 percent improvement in BPV potentiometer scale factor (BPV max - BPV min)/.945 in yards per second per revolution. This is attributed to the better trajectory and to the new policy of limiting BPV min.

Another parameter which is necessary for the TM solution is KVC, in the equation

$$VCRP = KVC \cdot AK \cdot APV \cdot TFR \cdot RD \times 10^{-2} \qquad (3\text{-}19)$$

which is a variation of

$$VCRP = AK \cdot (a/MV) \cdot APV \cdot TFR \qquad (3\text{-}20)$$

KVC becomes

$$KVC = \frac{a}{MV \cdot RD} = 9.61 \times 10^{-5} \text{ yards}^{-1} \qquad (3\text{-}21)$$

5. Tracking Parameters

The tracking parameters are L max, LPR max, VPR max, AK, DOR max, TFR max, and RFR max. The possible requirement for increasing L max for the 37-mm computer has been studied somewhat in the design department. Lead angle curves for various 800 mile per hour target courses have also been computed and are presented in Figure 3-20. Similar curves for other target speeds will be produced in the accuracy analysis and all parameters will be studied on the basis of hit probability. A final recommendation for L max will then be determined. Meanwhile, on the assumption that it might go as high as 37 degrees, a tentative value of cos L min was specified as 0.79.

LPR max and VPR max have been retained as 1600 and 1296 mils per second respectively until the target course studies are complete.

The aiding constant, AK may be changed as a result of the servo system studies. If greatly improved deflection servo response is predicted from that study, a reduction in AK would be possible. This would improve ST, as a result of the smoothing reduction. On the other hand, it may prove necessary to increase AK to improve stability at lower TM values. For the time being it will be assumed that AK will remain 0.33, as it was for Computer T26.

The maximum rates of range (DOR max) and time of flight (TFR max) will be determined by the maximum speeds of their respective servo motors. Until the servo studies progress further it will be assumed that the Kearfott R112 motor will be used. This motor produces a maximum speed of 10,000 rpm, as connected in Computer T26. This results in a DOR max of

$$\frac{10,000}{60} \times 20 \text{ yards/revolution} = 3333 \text{ yards per second} \qquad (3\text{-}22)$$

Assuming the same gear ratio is maintained to the ten-turn helipot (to overcome potentiometer friction), the new DOR max would be

$$\mathrm{DOR}_{\max} = \frac{\text{new potentiometer travel yards}}{\text{T26 potentiometer travel yards}} \qquad (3\text{-}23)$$

$$= 3333 \times \frac{8500}{6300} = 4497.4 \text{ yps} \tag{3-24}$$

Although this is considerably above the specified value of 3000 yards per second (for T26) it probably is justified because the servo has more yards to travel from one end to the other. However, it is thought that the servo should use two feedback potentiometers instead of one, making a total of four ten-turn potentiometers whose friction might total 5 to 6 inch ounces with ball bearing potentiometers. Although higher torques might exist in the three sleeve bearing potentiometers now used, no increase in new servo static accuracy is likely even if the component changes permit increasing the gain. This is because of the increase in servo scale factor from 6300 to 8500. Because of the prospective change from three to four Helipots, therefore, it is desirable to increase the motor gear ratio at some expense in DOR max. This would promise some gain in yards accuracy on the basis of servo load friction. A servo study is being made to show whether this will also benefit stability due to potentiometer resolutions. For the time being it was decided to improve slightly on the T26 gear ratio by going to 24 yards per revolution. This produces a DOR max of

---

[a] A 30,000 ohm potentiometer would have about [illegible] turns or 0.9 yards per winding.

A [illegible] ohm potentiometer would have about [illegible] turns or [illegible] yards per winding.

$$\frac{10{,}000}{60} \times 24 = 4000 \text{ yards per second} \qquad (3\text{-}25)$$

In the Computer T26 there was a gear ratio of 9:1 between the TF motor and potentiometer, which was found to be critical from the standpoint of limit stop inertia. To improve both TF acceleration and mechanical advantage against friction torques, this ratio is changed to 20:1. The motor shaft value will be the potentiometer shaft value divided by this gear ratio, or 0.05 seconds per revolution. TFR max becomes

$$\frac{10{,}000}{60} \times 0.05 = 8.33 \text{ seconds/second} \qquad (3\text{-}26)$$

Assuming instantaneous acceleration, it would require only 1.14 seconds for the TF servo to slew through its total travel at this rate, which is better than the 1.8 seconds required for the range servo.

The RF servo requirements have not been considered extensively as yet, although they should include high accuracy and a slewing time equal to that of the range servo. Until further study is completed, a motor to potentiometer ratio of 20.4 to 1 is recommended. This will apply to the three-turn potentiometers also, for the breadboard program. The resulting value of RFR max (for the ten-turn potentiometer) is

$$\frac{10,000}{60} \times \frac{.4}{20.4} = 3.27 \text{ seconds}^{-2} \qquad (3\text{-}27)$$

6. Summary

The tentative parameters so far determined are tabulated as follows

TABLE 3-1

COMPUTER SENSITIVITY PARAMETERS

Variable	Military Characteristic Value	Free Travel Objective	Free Travel (Breadboard)	Potentiometer Elec. Limit	Units
DP max	4500	-	-	-	yards
RF max	4.0*	4.0	3.92	4.0	mps/mil
RF min	.0556	.0556	0.0616	0	mps/mil
DO max	8287	8287	8287	8500	yards
DO min	244	200	213	0	yards
TF max	9.47	9.73	9.73	10.0	secs
TF min	0.25	0.20	0.27	0	secs

TABLE 3-2

DIFFERENTIAL BALLISTIC PARAMETERS

Variable	Value	Units
RD max	120	%
RD min	not determined yet	%
MV max	not determined yet	fps
MV min	not determined yet	fps

---

* RF max may have to be reduced in Model 2 to improve RF servo scale factors, especially if slide wire potentiometers prove not feasible. Furthermore, the course probability studies may influence this parameter.

TABLE 3-2 (CONT.)

Variable	Value	Units
WV max	not determined yet	mph
T max	not determined yet	°F
T min	not determined yet	°F
BPV max	1000	yps
BPV min	481.06	yps
KVC	9.61×10^{-5}	yards $^{-1}$

TABLE 3-3

COMPUTER TRACKING PARAMETERS

Variable	Value	Units
L max	not determined yet	mils
L min	0	mils
cos L min	0.79	-
AK	0.33	-
DOR	4000	yps
TFR	8.33	sec/sec
RFR	3.27	secs $^{-2}$

It is likely that the parameters which have not been specified will be established during the next quarter.

SECTION IV

SERVOS

A. INTRODUCTION

Investigation of the azimuth power control servo design was started about the middle of October, 1952. This servo is to be an electro-hydraulic servo of the conventional "A" and "B" end type, designed to meet the requirements of the new system. The initial decisions are based upon estimates of turret and gun inertia and data on the gun reaction torques expected if the Armour soft mounted gun is used. Computations for the Dixon gun and the hard mounted Armour gun will be made later when recoil force time diagrams are available. Maximum velocity and maximum acceleration requirements place further restrictions on these decisions. Mechanical packaging and substitution of some Stinger design influence the final choice and arrangement of basic components.

B. BASIC REQUIREMENTS

1. Performance

The maximum velocity of the turret is to be 90 degrees per second. The maximum uncontrolled acceleration of turret will be 200 degrees per second squared, while the maximum controlled acceleration will be 100 degrees per second squared.

2. Loads

Based on the Armour 37-mm soft mounted gun the estimated turret and gun inertia is expected to be 2000 slug ft^2. The average torque with one gun firing is 64,000 pound inches (figure 5-11).

3. Mechanical Considerations

The electric drive motor, transmission and associated controls, and the azimuth gear box are to be a packaged unit which will be removable from the top of the turret (figure 4-1). Investigation will be made to determine if the present Stinger gear box, whose gear ratio is 232 to 1, may be used.

4. Calculations Leading to Choice of Transmission and Components.

Torque required to accelerate 2000 slug ft^2 at $100/sec^2$ or 1.75 rad/sec^2 is

$$T_a = J_a = 2000 \text{ lb ft sec}^2 \times 1.75 \text{ rad/sec}^2$$

$$= 3500 \text{ lb ft at turret}$$

The hydraulic motor or "B" end torque required is

$$T_b = \frac{3500 \text{ lb ft}}{232} \times \frac{12 \text{ in}}{\text{ft}} = 181 \text{ lb in.}$$

The average gun reaction torque (one gun firing), assuming a torque arm of 21 inches and an average reaction force of 3055 pounds is

$$T_{gt} = 21 \text{ in.} \times 3055 \text{ lbs} = 64000 \text{ lb in.}$$

This torque reflected to the "B" end is

$$T_g = \frac{64000 \text{ lb in}}{232} = 276 \text{ lb in}$$

The total of these two torques is 457 pounds inches as seen at "B" end. The Vickers 3915 hydraulic transmission which is rated at 735 pound inches at 3000 pounds per square inch or 1088 pound inches at 4500 pounds per square inch is a likely choice based on these static considerations. The maximum pressures under the above mentioned conditions would be

$$\frac{735 \text{ lb in}}{3000 \text{ psi}} = \frac{457 \text{ lb in}}{P_m}$$

Solving: P_m = 1900 psi.

Considering the peak gun reactions in the static sense it will be found that the peak static torque reflected to the B end is

$$T_{gp} = \frac{9100 \text{ lbs} \times 21 \text{ inches}}{232} = 823 \text{ lb in}$$

The corresponding pressure is

$$\frac{735 \text{ lb in}}{3000 \text{ psi}} = \frac{823 \text{ lb in}}{P_{gp}}$$

P_{gp} = 3400 lbs per square inch.

Adding the pressure due to an acceleration of 100 $^\circ/\text{sec}^2$ we obtain 4140 pounds per square inch.

It is seen therefore, that from the static point of view pressures above 4140 pounds per square inch would not be exceeded and these would only obtain at points 30° from course crossover. Therefore, very simple relief valves of the spring and ball type may be used and these could be set to actuate above 4140 pounds per square inch. These may be mounted in the valve plate of the variable displacement pump (or "A" end) than eliminating external relief valves and the long piping associated with them. In this manner an effective reduction in "oil under compression" volume is obtained which is very definite advantage as will be discussed later.

These tentative conclusions may be altered due to either the use of a hard mounted gun whose fire may be synchronized or as a result of the dynamic analysis as indicated in paragraph D.

C. STROKING AND CONTROL MECHANISM

1. Pilot Valve and Power Piston

A power piston will be used to drive the "A" end yoke and a pilot valve will be used to actuate the power piston. It is tentatively decided to use a solenoid or a torque motor to drive the pilot valve similar to the ones presently used in Stinger. This is justified by the better frequency response of the solenoid over stroke servos. For example, the frequency response of a torque motor driving a pure inertia load and built by the Midwestern Geophysical Laboratory is down 5 db at 100 cycles per second, -50° phase shift at 100 cycles per second, and peak at about 300 cycles per second.

The pilot valve will be designed to yield maximum acceleration (200°/sec^2) when it displaced 0.015 inch from center position. This comparitively large displacement was chosen to reduce the effects of changing dimensions of the housing and linkages due to changing temperatures and also to relieve somewhat the dimensional tolerances. Further, 0.015 inch is a reasonable maximum displacement to require from a solenoid torque motor with about 20 to 40 milliamperes signal input.

The power piston will be built with a large diameter so that large forces will be available to drive the yoke, thus minimizing the effect of load reaction forces on the "A" end.

The power piston will have an area of 2 square inches and a stroke of 1.687 inches. The required volumetric rate of flow into the power piston to yield maximum acceleration is 0.485 gallon per minute.

2. Electric Drive Motor

The pump must be run at a constant speed of 3600 revolutions per minute if the gear ratio is to be 232 to 1. If the electric drive motor runs at a different speed as in caliber .60 Stinger, it is necessary to interpose a gear box between the motor and the "A" end. Regardless, the required horsepower of the motor may be estimated as follows.

Maximum Required Horsepower = hp = $J_T V_T A_T$ + power losses

in which J_T = total turret inertia = 2000 slug ft^2

V_T = maximum turret velocity = $90°/sec$ = 1.57 rad/sec

A_T = maximum turret controlled acceleration = $100°/sec^2$ = 1.75 rad/sec^2.

Power losses: estimated at 2 hp (power required to pump control pressure oil, system replenishing pressure oil, and pump losses).

$$\text{maximum horsepower} = 2 + \frac{2000 \text{ lb ft sec}^2 \times 1.57 \text{ rad/sec} \times 1.75 \text{ rad/sec}^2}{550}$$

$$= 12 \text{ horsepower}$$

Thus an electric motor is required which has good speed regulation over the range of 2 to 12 horsepowers*. This is a conservative figure and is based upon the improbable condition that the maximum velocity and maximum acceleration will occur at the same time. However, it should be noted that this condition does occur during breadboard test when the test constant-acceleration course is used to evaluate servo acceleration errors. It is believed that this conservative estimate is justified to compensate for possible increase in inertia over that estimated.

---

* Good speed regulation is required in order to maintain linear errors due to accelerations regardless of the horsepower demanded of the system.

The azimuth electric drive motor presently used in Stinger (Diehl SS FD168-2200-1) has a speed regulation of 7.5 percent over this range.

3. Other Mechanical Considerations

The hydraulic control system will be built along lines similar to that of the present Stinger azimuth system. Specifically the control pressure pump, replenishing pump, solenoid, pilot valve, and the stroke feedback mechanism will be integral with the basic pump or "A" end. An oil cooling system will be included operating from the overflow oil of the two pumps. This leads to the advantage of being able to use a smaller pump, possibly built into the "A" end cover, and locating an oil cooling system remotely with respect to the power controls.

The pilot valve - solenoid linkage will be redesigned. It is presently contemplated that a 0.020 inch diameter steel wire will be used to transmit motion from the solenoid to the pilot valve. This wire would be fixed to the solenoid arm and fixed to the back end of the pilot valve sleeve. Balancing adjustments will be made on the sleeve outside of the case.

D. DYNAMIC CONSIDERATIONS

1. General

The preceding considerations were based on the static characteristics of the system which must necessarily be satisfied. However, the system is dynamic and the previous decisions must be examined in this light. The dynamic analysis may show that the above choice is entirely inadequate and a different size transmission may have to be chosen. The following work has been done.

2. Azimuth Power Control

The azimuth power control servo is broken down into the block diagram shown in figure 4-2.

The notation used is

$\theta_o(t) = 232 \times \theta'_o(t)$

$\theta_i(t)$ input to azimuth power control servo

$\theta'_o(t)$ output of azimuth power control servo (turret position)

$\epsilon(t)$ error equal to $(\theta i - \theta o)$ if $H = 1$

$\theta_B(t)$ "B" end or hydraulic motor position

K equivalent system spring constant reflected to "B" end

J_1 equivalent gearing and "B" end inertia reflected to "B" end

J_2 equivalent load inertia reflected to "B" end

$T_L(t)$ load disturbance due to guns firing reflected to "B" end

$y(t)$ the "A" end yoke displacement from neutral (radians)

$G_1(t)$ the servo transfer function

$H(t)$ is the major loop feedback transfer function

$G_2(t)$ the hydraulic transmission plus load transfer function

The quantities which are functions of time are indicated by (t). All quantities have been reflected to the "B" end shaft value as determined by the 232 to 1 gear ratio.

3. Transfer Functions

The equations for G_2 will be developed. These are

$$\frac{\theta_o(t)}{y(t)} \text{ with } T_L(t) = 0 \tag{4-1}$$

This formula will be used for the servo design study.

and

$$\frac{\theta_o(t)}{T_L(t)} \text{ (with } y(t) = 0) \tag{4-2}$$

This formula will be used to investigate the effect of gun firing on turret motion.

These equations will be developed as open loop equations with H = 0.

4. Transmission

The transmission consists of a variable displacement pump or "A" end, a fixed displacement motor or "B" end, and connecting pipes. Associated with these components are the following parameters

$y(t)$	"A" end yoke displacement from neutral (radians)
$Sp(t)$	quantity of oil pumped per unit of y (ft^3/sec per radian of y)
$Qp(t)$	quantity of oil pumped ($S_p y$ ft^3/sec)
L	Leakage coefficient (ft^3 per sec per lb per ft^2 of differential line pressure)
$Q_1(t)$	Leakage (= L P ft^3/sec)
$P(t)$	differential line pressure (lbs/ft^2)
$Qm(t)$	motor flow (= dm $\cdot \frac{d\theta_B}{dt}$ ft^3/sec)
dm	motor displacement (ft^3/rad).
$\frac{d\theta_B(t)}{dt}$	"B" end or hydraulic motor velocity (rad/sec)
Qc	Oil flow due to oil compression (= $\frac{\Delta V}{\Delta t}$ ft^3/sec)
ΔV	Change in volume of oil under compression (= $\frac{V}{B} P$ ft^3)
V	Volume of oil under compression (ft^3)
B	Bulk modulus of oil (lbs per ft^2)

5. Pump Pressure Equations

$$P = \frac{J_1}{dm} S^2 \theta_B - (\theta o - \theta_B) \frac{K}{Dm} \qquad (4\text{-}3)$$

where $S = \frac{d}{dt} = jw$ (usual operator notation)

$$Q_1 = LP \frac{LJ_1}{dm} S^2 \theta_B - \frac{LK}{dm} (\theta o - \theta_B) \qquad (4\text{-}4)$$

$$Qm = dm \frac{d\theta_B}{dt} = dmS\theta_B \qquad (4\text{-}5)$$

$$Qc = \frac{dV}{dt} = \frac{V}{B} \frac{dP}{dt} = \frac{Vd}{Bdt} \left[\frac{J_1}{dm} S^2 \theta_B - (\theta o - \theta B) \frac{K}{dm} \right]$$

$$= \frac{V}{B} \frac{J_1}{dm} S^3 \theta_B - S (\theta o - \theta_B) \frac{KV}{Bdm} \qquad (4\text{-}6)$$

$$Qp = Q_1 + Qm + Qc + S_p Y \qquad (4\text{-}7)$$

$$S_p Y = \left[\frac{LJ_1}{dm} S^2 \theta_B - \frac{LK}{dm} (\theta o - \theta_B) \right] + dm\, S\, \theta_B + \left[\frac{VJ_1}{Bdm} S^3 \theta_B - S (\theta o - \theta_B) \frac{KV}{Bdm} \right] \qquad (4\text{-}8)$$

Solving Eq. (4-8) for θ_B

$$\theta_B = \frac{s_p Y + \frac{LK}{dm} \left[1 + \frac{V}{BL} s \right] \theta o}{\frac{LK}{dm} \left[\frac{VJ_1}{BLK} S^3 + J_1 / K\, S^2 + \left[\frac{dm^2}{LK} + \frac{V}{BL} \right] S + 1 \right]} \qquad (4\text{-}9)$$

6. Load Torque Equations

$$J_2 S^2 \theta o = T_L + (\theta_B - \theta o) K \qquad (4-10)$$

Solving Eq. 4-10 for 9o

$$\theta o = \frac{K \theta_B + T_L}{K\left[\frac{J_2}{K} S^2 + 1\right]} \qquad (4-11)$$

7. Equations 4-9 and 4-11 suggest the block diagram of figure 4-3.

8. Hydraulic Coefficients

The following hydraulic coefficients were obtained from Vickers Data Summary SE-16a and are for the 3915 units.

$Sp = 1.519\ {}^{in^3}/rev = .1\,{}^{ft^3}/sec$ per rad of y

L (total for "A" and "B" end)

$= 2 \times 0.62\ in^3/sec/\ 1000\ psi = 4.95 \times 10^{-9} \frac{ft^5}{sec\ lb}$

$dm = 1.519\ in^3/rev = 1.41 \times 10^{-4}\ {}^{ft^3}/{}_{rad}$

The bulk modulus coefficient is that of the oil presently used on Stinger.

$B = 238{,}000\ lb/in^2 = 34.3 \times 10^6\ {}^{lb}/ft^2$

The volume of oil under compression was estimated at $11\,{}^{in^3}$ (based on 30 inches of pipe length; 3/4 inches in diameter plus the oil within "A" and "B" end).

9. Mechanical Coefficients

Although the turret and gun inertias (J_2) have been estimated at 2000 slug ft^2 at the turret, the inertia J_1 and the spring constant have not yet been estimated. It is anticipated that J_1 will be very small and K very large which will result in a considerable simplification of the equations.

10. Transfer Function Coefficients

The transfer function coefficients presently known are

$\frac{L}{dm}(K)$	$3.48 \times 10^{5} \frac{ft^2}{sec\ lb}$ (K lb ft)
S_p	.1 ft^3/sec per rad of y
$\frac{V}{BL}\left[\frac{J_1}{K}\right]$	.0374 sec $\left[\frac{J_1}{K}\ \frac{lb\ ft\ sec^2}{lb\ ft}\right]$
$\left[\frac{J_1}{K}\right]$	$\left[\frac{J_1}{K}\ \frac{lb\ ft\ sec^2}{lb\ ft}\right]$
$\frac{dm^2}{L}\left[\frac{1}{K}\right]$	4.05 lb ft sec $\left[\frac{1}{K\ lb\ ft}\right]$
$\frac{V}{BL}$	.0374 sec
$\left[\frac{J_2}{K}\right]$	$\left[\frac{J_2}{K}\ \frac{lb\ ft\ sec^2}{lb\ ft}\right]$
$\left[\frac{1}{K}\right]$	$\left[\frac{1}{K\ lb\ ft}\right]$

The block diagram with known coefficients inserted is shown in figure 4-4.

11. Output versus Power Piston

For $T_L(t) = o$
$$\frac{\theta o\ (t)}{y\ (t)} = \frac{.1\ G_{21}\ G_{22}}{1 - G_{21}\ G_{22}\ H_2} = G_2' \qquad (4\text{-}12)$$

Substituting transfer functions

$$\frac{\theta_o(t)}{y(t)} = \frac{.1}{S\left\{ .131 \times 10^{-5} \frac{J_1 J_2}{K} S^4 + 3.48 \times 10^{-5} \frac{J_1 J_2}{K} S^3 + \left[14.1 \times 10^{-5} \frac{J_2}{K} + .131 \times 10^{-5} J_2 + .131 \times 10^{-5} J_1 \right] S^2 + \left[3.48 \times 10^{-5} J_2 + 3.48 \times 10^{-5} J_1 \right] S + 14.1 \times 10^{-5} \right.} \qquad (4\text{-}13)$$

12. Output Versus Load Disturbance with $y(t) = 0$

$$\frac{\theta_o(t)}{T_L(t)} = \frac{10}{KG_{21}} \cdot \frac{\theta_o(t)}{y(t)} = 3.48 \times 10^{-5} \left[.0374 \frac{J_1}{K} S^3 + \frac{J_1}{K} S^2 + \left[\frac{4.05}{K} + .0374 \right] S + 1 \right] \frac{\theta_o(t)}{y(t)}$$

$$= G_2'' \qquad (4\text{-}14)$$

13. Application of Equations (4-12) and (4-13)

The equation $\frac{\theta o\ (t)}{y\ (t)} = G_2$ for $T_L(t) = o$ will be used in the development of the servo. The multiplication of G'_2 by G_1 yields the open loop transfer function of the servo. In the initial design work, neglecting certain terms will prove expedient in indicating the proper approach, order of magnitude, and kind of transfer functions necessary. For example, if K approaches ∞ and J_1 approaches 0, G'_2 will reduce to

$$G'_2 = \frac{.1}{S\left\{.131 \times 10^{-5}\ J_2 S^2 + 3.48 \times 10^{-5} J_2\ S + 14.1 \times 10^{-5}\right\}}$$

$$= \frac{710}{S(.000346\ S^2 + .0915\ S + 1)} \qquad (4\text{-}15)$$

Considering SG'_2 (which is simply the transmission function of "B" end velocity versus yoke position) we find the peaking frequency of the transmission as

$$\frac{1}{\omega_o^2} = .000346$$

$$\omega_o = 53.6$$

$$f_o = \frac{53.6}{2\pi} = 8.55 \text{ cps}$$

The damping coefficient is found from

$$\frac{2\zeta}{\omega_o} = .0915$$

$$\zeta = .245$$

This damping coefficient corresponds to about a 6 db peak.

It should be noted here, although it has not been shown explicitly, that the coefficient of S^2 is proportional to $\frac{V}{B}\frac{J_2}{dm}$ and that for ω_o to be large this quantity should be small. This is the reason for wanting the volume of oil under compression kept small.

Further the coefficient of the S term is proportional to $\frac{LJ_2}{dm^2}$ and thus the magnitude of the peak is limited by the leakage.

This expression may be further simplified by neglecting the peaking effect and assuming a magnitude-frequency curve for G_2' of the form

$$G_2' = \frac{710}{j\omega\left\{1 + \frac{j\omega}{53.6}\right\}^2}$$

This is plotted with a decreasing slope of 20 db per decade to $\omega = 53.6$ and then 60 db per decade.

This procedure simplifies the initial design work. The final design would be checked with the complete transfer function involved.

14. Application of Equation (4-14)

The equation $\frac{\theta o\ (t)}{T_L\ (t)} = G_2''$ will be used to find the effect of disturbing load torques on the system. This investigation may be made in two parts

(a) Considering the effect with the servo open loop (H = 0) and with y held in the natural or zero velocity position.

(b) Considering the effect with the servo loop closed.

The former may be investigated rather early in the study because it involves only the use of 3 unknown constants, J_1, J_2, and K.

However, the latter investigation depends upon the development of the servo and the associated transfer functions. This investigation is necessarily delayed to a later date.

The method of investigation will be as follows: The Fourier series coefficients for force-time curve of figure 5-11 are computed as outlined in Section V, paragraph A(6). Each component sine and cosine wave will be applied to the transfer functions separately and the output magnitude and phase calculated. These outputs will then be summed to give the resulting effect of firing one gun.

E. BREADBOARD ASSEMBLY

The actual breadboard work is progressing as follows: The "A" and "B" ends have been obtained on a consignment basis from Vickers. An electric drive motor and a suitable mounting table have been assigned. The power piston and bracket are mounted on the "A" end. Almost all the external pumps and associated fixtures are available and are now being assembled.

F. FUTURE ACTIVITY

Data will be taken on the tentatively proposed pilot valve and solenoid in order to obtain needed design information. Study is being done to determine the coefficients necessary in order to use equations 4-13 and 4-14. A preliminary servo design study will be made to determine the feasibility of using a magnetic amplifier in place of the conventional amplifier.

No work has been started on the design of the elevation power control system or the remaining servos.

SECTION V

TURRET AND VEHICLE STUDIES

A. AMMUNITION STORAGE, AMMUNITION FEED, AND GUN MOUNTING STUDIES

1. Ammunition Storage

A crude mock-up of a shelf-type ammunition racking system was made (figure 5-1). Belted rounds were hung in vertical columns suspended from two rounds which rested on the shelf. The links passed thru a slot in the center of the shelf. A band sawed sprocket simulated the booster. On the basis of trials with this mock-up this simple racking scheme appears feasible and little further study will be devoted to the ammunition storage problem.

2. Booster Performance

Given the gun firing rate, the round weight, the length of the external chute, and the assumption that the belt tension immediately above the booster is zero, the design problem concerning the booster is to find the time available for the booster to come up to firing speed and the motor performance required to accomplish this. The preliminary analysis of ammunition booster action described in the first quarterly report assumed that there were twenty close-coupled rounds in the external chute and neglected the effect of link flexibility. These assumptions would be correct for the first burst after reloading. However, if the ammunition in the magazine were not expended in the first burst, (a likely event) it is conceivable that the booster could push perhaps five rounds into the chute upon completion of the first burst. In this event, at the start of the second burst there would be only five close-coupled rounds in the chutes, the remaining rounds being coupled together by extended links. The time available for the booster to come up to speed would then be correspondingly shorter. An attempt was made to analyze the action of the belt by including belt flexibility. This analysis proved quite complex and was discarded in favor of the analysis described below.

The stretch of the belt during the booster accelerating period is made up of two effects:

(a) The stretch of the 20 round belt due to link flexibility.

(b) The extension of the belt arising from the fact that the five rounds are close-coupled at the start of the burst; during the burst they are extended-coupled.

It is reasonable to assume that the link stretch will be maximum near the gun and zero immediately above the booster where the belt tension is assumed to be zero. With a maximum permissible link stretch of 0.3 inch per round such an assumption leads to a maximum belt extension of 1.1 inches during the period in which the booster is accelerating.

The extension of the belt due to the lost motion in the links is 3.1 inches; the total permissible belt extension is then 4.2 inches corresponding to 1.3 rounds. This conversion is made because the following analysis is carried out in rounds per minute.

If we assume that a 28 volt, d-c motor is used to power the booster, it might have a sprocket force time curve similar to the curve of figure 5-2, which has been simplified for this analysis. The sprocket force would be high at stall conditions and would decrease rapidly to the steady state condition where it might be 41.8 pounds corresponding to the weight of the rounds hanging on the booster in the magazine.

During the accelerating period when $0 < t < t_a$, we can express the booster force (f), in pounds, in terms of sprocket stall force (F_s) and the time in seconds for acceleration (t_a) as follows.

$$F = F_s - \left\{ \frac{F_s - 41.8}{t_a} \right\} t \qquad (5-1)$$

The booster is supporting the mass of the 10 rounds still in the magazine or about 1.3 slugs.

The number of rounds per foot of belt $= \frac{12}{3.25} = 3.69$

The belt acceleration at the booster will be

$$a = \frac{F_s}{3.69 \times 1.3} - \left[\frac{F_s - 41.8}{3.69 \times 1.3 \; t_a} \right] t$$

$$= \frac{F_s}{4.79} - \left[\frac{F_s - 41.8}{4.79 \quad t_a} \right] t \qquad (5\text{-}2)$$

At the end of the time t_a, the booster speed will equal the firing rate of the gun, 16.6 rounds per second (1000 rounds per minute), or

$$\int_0^{ta} a\,dt = 16.6$$

$$= \int_0^{ta} \left[\frac{F_s}{4.79} - \frac{F_s - 41.8}{4.79 \; t_a} t \right] dt \qquad (5\text{-}3)$$

carrying out the integration and simplifying gives

$$ta = \frac{159}{F_s + 41.6} \qquad (5\text{-}4)$$

This expresses, under the assumed conditions, the time required for the booster to come up to firing speed as a function of booster stall force. During this accelerating time, the total number of rounds entering the chute will be given by the expression

$$\int_0^{t_a}\int_0^{t} a \, dt \, dt \qquad (5\text{-}5)$$

The rounds leaving the chute will be $16.6\ t_a$.

The excess of the number of rounds leaving the chute over the number entering the chute will be the permissible stretch of the belt, 1.3 rounds, or

$$16.6\ ta - \int_0^{t_a}\int_0^{t} a \, dt = 1.3 \qquad (5\text{-}6)$$

Substituting equations (5-2) and (5-4) into equation (5-6) gives

$$F_s = 652 \text{ lbs.}$$

and substituting this value of F_s into equation (5-4) gives

$$t_a = .20 \text{ seconds.}$$

Total belt pull at the booster at the start.

$$\left\{\text{accelerating force}\right\} + \left\{\text{friction}\right\} + \left\{\begin{array}{l}\text{weight of rounds}\\ \text{hanging from booster}\end{array}\right\}$$

$$652 + 100 + 42 = 794 \text{ lbs.}$$

Assuming a 56 to 1 gear ratio between motor armature and sprocket, the required motor torque to produce this belt pull $= \dfrac{794 \times 4.8}{56} = 68.1$

Estimated inertia of booster armature, gears, and sprocket is .016 in-lb-sec^2.

Required average armature acceleration for a motor having a full load speed of 6000 rpm

$$a = \frac{6000 \times 2\pi}{60 \times .20} = 3140 \text{ rad/sec}^2$$

Peak armature accelerating torque $= Ja = 2(.016 \times 3140)$ in lb

$= 100.5$ in lb

Peak booster motor torque = 100.5 + 68.1 = 168.6 in. lb at start.

For a gun having a firing rate of 500 rounds per minute with a d-c booster, the corresponding values are:

$$F_s = 161.6 \text{ lb.}$$

$$t_a = \frac{75.6}{F_s + 41.6} = .39 \text{ sec}$$

Peak motor torque = 18 in.lb. at start.

In the event that the Stinger main power supply were changed to a 115-volt, 400-cycle, three phase system, the required booster motor performance has been analyzed based on the use of an 11,000 rpm a-c motor with different starting characteristics. For such a motor figure 5-3 shows the assumed booster sprocket force vs. time relation.

In a manner similar to that described above, the corresponding values for a 1000 round per minute gun with an a-c booster are

F_s = 570 lbs.
t_a = .14 sec.
Peak motor torque = 146 in-lb.

and for a 500 round per minute gun

F_s = 127 lbs.
t_a = .31 sec.
Peak motor torque = 19.6 in-lb.

The design of the booster shown in the first quarterly progress report assumes the performance required of the d-c booster for a 1000 round per minute gun. Figure 5-4 shows the d-c booster for a 500 round per minute gun. No layouts of a-c boosters have been made, though a preliminary investigation showed that the a-c motor frame sizes for the required torques were not reasonable.

Because of the large motor currents expected, it is felt that a current overload relay would be more suitable for protective purposes than a stall switch in the event of a gun or feed jam.

3. Gun Mounting

During the last quarter design studies of mounting schemes for the Armour gun were started. A construction similar to the welded cradle and torque tube assembly proposed in the first report for the Dixon gun is shown for the Armour gun in figure 5-5. This construction, although probably quite rigid, would be unwieldy to manufacture since accurate machining of the surfaces which support the guns would be carried out on the complete assembly.

An alternate method of mounting either of the two guns on an interchangeable torque tube has also been laid out. The probable schedules for gun development and mount development are such that a final decision on which of the two 37-mm guns now under development will be used for Stinger may not be made until final mount design is well under way. With this in mind, a bolted construction seemed advisable rather than the welded scheme shown in figure 5-5. An extension welded to the receiver of the Armour gun and in turn bolted to the torque tube is shown in figure 5-6. These bolts would be reamed in place after proper relative alignment of the two guns had been obtained about the elevation axis. Alignment in the slant plane would be machined in.

Such an arrangement does not seem feasible on the Dixon gun. As a result a cradle is proposed (figure 5-7) which can be bolted to the torque tube. Whether such an arrangement will be rigid enough to obtain acceptable gun dispersion patterns will require further study when more complete kinematic diagrams of the gun reactions are available.

4. Equilibrator Springs

Work has continued on the equilibrator spring problem. Studies of spiral springs such as illustrated in figure 5-8 for the Armour gun and figure 5-9 for the Dixon gun have shown that this type of spring requires too much space compared with that needed for an equivalent helical spring even though the torque diameter be reduced as shown in figure 5-8.

Accordingly, it is proposed that a helical spring, shown in figure 5-10, for the Armour gun, be used in Stinger. This spring is designed to operate at a maximum extreme fibre stress of 125,000 pounds per square inch in accordance with the results of the conference at Watertown Arsenal.

5. Links

A layout of the proposed new link for the 17-inch round in the Dixon guns was received. (Dixon drawing C20C-260). It was further understood that Armour was working on a push through type of link, although no drawings of this link have as yet been received. It would seem that the rounds hanging in the magazine would be more securely held by a push through type of link. In operating the magazine mockup referred to earlier, considerable difficulty was experienced with the old links in that they released the rounds easily. No attempt had been made to duplicate the weight of the rounds in the mockup (the mocked up rounds weighed about six pounds. This tendency to release rounds from the links might not occur in a static magazine, but might be dangerous in a moving vehicle or when the rounds were being handled by the booster.

6. Recoil Forces

A typical recoil force - time diagram (figure 5-11) was received from Armour Research Foundation for the soft mounted 37-mm gun, T172, firing at 600 rounds per minute at normal temperature. An attempt has been made to compute its equivalent in the form of a sine-cosine Fourier series for use in the power control servo analysis. Such a series would have the form

$$F = A_0 + \sum_{n=1}^{\infty} A_n \sin n\omega t + \sum_{n=1}^{\infty} B_n \cos n\omega t \qquad 5\text{[illegible]}$$

The curve was divided into m small parts of length (Δt) along the time axis and the ordinates (F) at each point measured. The average steady-state force is

$$a_o = \frac{\sum_{p=0}^{m} F_p \Delta t}{M\Delta t} = 3055 \text{ lbs}$$

The first harmonic was obtained by considering that

$$M\Delta t = 2\pi$$

and computing the corresponding angle (Θp) to each ordinate,

Then

$$A_1 = \frac{2\sum_{p=1}^{m} F_p \sin \theta p}{m} = 5995 \text{ lb.}$$

$$B_1 = \frac{2\sum_{p=1}^{m} F_p \cos \theta p}{m} = -899 \text{ lb.}$$

Computation of the next six harmonics was carried out in a similar manner. The results are tabulated as follows

TABLE 5-1

FOURIER SERIES COEFFICIENTS

A_0	3055		
A_1	5995	B_1	-899
A_2	687	B_2	-1591
A_3	76	B_3	-130
A_4	76	B_4	-166
A_5	481	B_5	-524
A_6	-55	B_6	232
A_7	-49	B_7	185

B. STRUCTURE STUDIES

1. Upper Structure

Design work on the upper structure has been carried out under the assumption that 1/2-inch armor would be used to protect the components inside the structure. It is felt that the more complex contours of the pedestal (such as rear door and the top which humps over the trunnion and also forms a foundation for the scanner) would be more easily fabricated as castings. Making the top of a casting would facilitate assembly since the trunnion and elevating gear could be installed before this casting was bolted in place (figure 5-12). Thought has been given to locks to fasten the door in place. One form of a suitable lock is shown in figure 5-13.

2. Lower Structure

With receipt of vehicle drawings from Detroit Arsenal, design work was started on the Stinger lower structure and on adaptation of the vehicle to Stinger. It was soon evident that the bottom support scheme used for the twin 40-mm turret in the vehicle would not be suitable for Stinger; more efficient use of the available volume in the vehicle would be required. Work was concentrated on a top-mounting scheme like that presently used for the caliber .60 Stinger. Clearance available between the turret and the vehicle walls are shown in figures 5-14 and 5-15. The large clearances available encouraged the extension of the turret out under the main azimuth driving gear. Assembly of the lower structure bearing will not be compromised since these extensions are to be bolted to the main welded frame.

Experience in the manufacture of the main azimuth bearing and gear assembly demonstrated that it would be desirable to eliminate welding of the main frame to the inner race of the bearing, if possible. Accordingly, a design study of this problem was made and the proposed construction is shown in figure 5-16 which also shows the proposed increase in lower structure diameter below the bearing.

3. Azimuth Bearing Loads

Analysis was made of the effect of the expected firing loads on the bearing with a view to determining if the bearing used for the caliber .60 Stinger could be used. With a 15000 pound recoil force of one gun acting as a static force, it can be shown that a load of about 33,000 pounds is produced on the inner race of the bearing where the main frame is attached. Considering the inner race as a beam resting on an elastic foundation, the following analysis was made.

The foundation modulus is the function which expresses the ratio of unit load to unit deformation in the beam support (in this case the balls supporting the inner race). Using formulas given by Roark* the deflection of a ball against the outer race is calculated.

Let: r_1 = race groove radius = -.663 in.

r_1' = race radius = -37.50 in.

$r_2 = r_2'$ = ball radius = + .625 in.

E = Young's Modulus = 30×10^6

V = Poissons Ratio = .26

---

* Roark, formulas for stress and strain, second ed., page 277, McGraw-Hill Book Company, 1943.

$$K = \frac{4E_1}{3(1 - V^2)} = 42.9 \times 10^6 \qquad (5\text{-}8)$$

$$\delta_1 = \frac{4}{\frac{1}{r_1} + \frac{1}{r_1'} + \frac{1}{r_2} + \frac{1}{r_2'}} = 2.4 \qquad (5\text{-}9)$$

$$\theta_1 = \text{arc cos } \frac{1}{4}\, \delta_1 \left[\frac{1}{r_1} - \frac{1}{r_1'}\right] = \text{arc cos } .888 = 27.4° \qquad (5\text{-}10)$$

from the chart given in Roark,

$\alpha_1 = 2.92$

$B_1 = .47$

$\lambda_1 = 1.41$

In a similar manner, for the deflection of a ball against the inner race

$\delta_2 = 2.327$

$\theta_2 = 26.7°$

$\alpha_2 = 3.0$

$B_2 = .47$

$\lambda_2 = 1.4$

The total deflection of the ball against the two races (P is the load on the ball in pounds).

$$y = \lambda_1 \sqrt[3]{\frac{P_2}{K^3 \delta_1}} + \lambda_2 \sqrt[3]{\frac{P_2}{K^2 \delta_3}} \qquad (5\text{-}11)$$

$$= .1729\ P^{2/3} \times 10^{-4}$$

The deflection of the ball and races against the ball load is plotted in figure 5-17.

$$C = \text{Foundation Modulus} = \frac{P}{yl}$$

where P and y are as before; l = ball spacing along the race = 1.93 inches.

Values of C for various values of P are shown in figure 5-18.

Let P = recoil force acting = 35000 lbs.

I = Bending moment of inertia of inner race
= 1.224 in.^{4}

$$P_{max} = \frac{Pl}{2}\sqrt[4]{\frac{C}{4EI}} \qquad (5\text{-}12)$$

$$= 307.5 \sqrt[4]{C}$$

Since C is a function of P, solving by trial gives P = 8600 lb.

The original computations for this bearing indicated that a safe force per ball was about 9400 pounds. However, computations of the contact stresses for both ball loads will be checked during the next quarter.

The derivation of the equation used in the above computations is based on an infinitely long beam. In using the analysis it was felt that the inner race was sufficiently flexible with respect to the foundation modulus that a reasonable approximation of the maximum ball load could be found in that way. A more complete analysis of the ball action led to a differential equation of the form

$$\frac{d^4y}{dx^4} = K_1 + K_2x^2y + K_3x^4y + K_4y^2 \qquad (5\text{-}13)$$

where y is the deflection of the inner race
x is the length of the race from the point of application of the load
K_1, K_2, K_3, and K_4 are constants

The solution of this equation is incomplete at this time.

4. Azimuth Power Transmission Spring Constant

In the servo equations developed in Section IV, a measure of the deflection of the azimuth power transmission under load is required. Since the gear box will be similar to the one used on the caliber .60 Stinger, it was felt that a deflection analysis of that unit would give a measure of the spring constant of a box which may be redesigned. In addition, such an analysis would show up possible methods of improving the stiffness of the transmission.

The following factors were considered

(a) Torsional deflection of shafts
(b) Torsional deflection of gear blanks
(c) Bending and compressive deflection of the gear teeth

The following factors were ignored as probably contributing little flexibility to the system

(a) Radial deflection of the bearings
(b) Bending deflection of the shafts

Throughout the analysis it has been assumed that the various deflections are linear functions of the applied loads. This is not quite true, especially with respect to the compressive deflection of the gear teeth. In this case the expected deflection under the maximum applied load was computed and the corresponding spring rate determined. Such a method leads to a total spring rate based on the maximum expected system torques; the transmission will be somewhat softer for lighter loads.

Torsional deflection of a gear blank

Let G = Torsional modulus

P = Applied tangential load - pounds

r_i = inner radius of blank

r_o = outer radius of blank

θ = angular deflection of blank - radians

t = thickness of blank

$$G = \frac{P/2\pi r t}{r\,\frac{\Delta\theta}{\Delta r}} = \frac{P}{2\pi r^2 t\,\frac{\Delta\theta}{\Delta r}}$$

$$\frac{\Delta\theta}{\Delta r} = \frac{P}{2\pi r^2 t}$$

$$\frac{\theta}{P} = \int_{r_i}^{r_o} d\theta = \frac{1}{2\pi t G}\int_{r_i}^{r_o}\frac{dr}{r2} = \frac{1}{2\pi G t}\left(\frac{1}{r_i} - \frac{1}{r_o}\right)$$

$$= \frac{1.328 \times 10^{-8}}{t}\left(\frac{1}{r_i} - \frac{1}{r_o}\right)$$

Torsional deflection of shaft = θ

$$\frac{\theta}{T} = 5.31 \times 10^{-8}\ \frac{t}{r^4}$$

Total deflection of mating gear teeth = δ

$$\frac{\delta}{P} = \frac{1}{FS}\ \frac{Z_1 + Z_2}{Z_1\ Z_2}$$

where F = face width (inches)

y = Lewis form factor

Z = Elasticity form factor = $\frac{y}{.242 + 7.25y}$

E = Youngs Modulus

P = Applied load

Carrying out the indicated computations for each member of the gear train, referring all computations to the B-end shaft and summing gives the torsional spring constant for the azimuth power gear box

$$K = 46.88 \times 10^{-6} \text{ rad/in lb.}$$

5. Rotational Moment of Inertia

To enable the analysis of the power control to get under way, a preliminary estimate of system moments of inertia in the elevation and azimuth planes was made. These estimates were 1256 slug ft^2 in elevation and 2000 slug ft^2 in azimuth, both of which were based on use of the Armour gun.

More detailed computations of the moments of inertia have been undertaken. The only one which is complete at this time produced a value of 1078 slug ft^2 for the moment of inertia in the elevation plane using the Armour guns.

C. VEHICLE

Clearances between the vehicle walls and the Stinger lower structure are discussed in paragraph B of this section. Since the twin 40-mm turret presently used in the vehicle is supported from below, the present hull structure around the turret opening is not designed for rigidity. Mounting the Stinger main bearing to the deck plates will require some reinforcing, especially since the hatch openings in front and the engine compartment in the rear reduce any inherent rigidity afforded by connection to the front and rear walls of the vehicle. Accordingly, a proposed vehicle modification to provide more adequate support of the turret against road shocks and firing loads is shown in figure 5-19.

D. ELECTRICAL POWER SUPPLY

The caliber .60 Stinger uses 28-volt, d c for primary power. One of the main reasons for using such a primary supply on the caliber .60 Stinger was the requirement for emergency battery operation on the self propelled mount; the trailed vehicle has no batteries for emergency operation. Consideration is being given to changing the primary power source from 28-volts, d c to 115-volts, 400-cycle, three phase a c.

The advantages of such a change include

(a) Smaller motors may be used for azimuth and elevation power drives.
(b) Radio noise problem is simplified.
(c) Line voltage drops will be reduced.

(d) Less copper will be needed.

(e) Maintenance on a-c motors is low.

(f) Fewer commutators will be used.

(g) Inverters will not be necessary.

The disadvantages of such a change include

(a) Filament transformers may be necessary.

(b) Dynamotors may still be necessary for 250 volt d-c requirements since rectifiers might not have satisfactory voltage regulation.

(c) Electronic power supplies to take the place of the dynamotors might be large.

(d) Good speed regulation of the alternators would be necessary.

(e) Some d c would still be necessary

(f) Relays and starting boxes would be larger.

(g) Battery operation would be eliminated.

Further consideration of this change-over is being given to assess the detailed effect of the change.

Provision has been made on the self propelled vehicle for one generator mounted on the main engine and for a second generator driven by an auxiliary engine. For the relatively high electrical power requirements of Stinger over that for the turret presently installed in the vehicle, this would mean that both engines would be running when Stinger was in use. Alternatives to this scheme would involve mounting two 15 KW generators on the main engine or of providing sufficient auxiliary engine power to drive these generators. In this connection consideration has been given to the use of small gas turbines such as are made by Air Research. A suitable turbine package would be about 25 x 14 x 31 inches to which the generator or alternator could be bolted. Fuel would be pumped from the main engine tanks by a small booster. Figure 5-20 shows a trial installation on the vehicle sponsor. This would be unsatisfactory with respect to road clearance and vulnerability. However, it is felt that use of auxiliary engines for driving the generator merits further consideration in view of the reduction in main engine operating time which could be obtained.

APPENDIX A

A GLOSSARY OF DIRECTOR SYMBOLS

37-mm COMPUTER STUDY

For the most part the symbols used in the Stinger have been obtained by combining the initials of each word of each term. Since in many cases the same words are used in different combinations, there are actually relatively few terms to be memorized; after these are learned, additional terms will be recognized by the different combinations. Only English letters and capitals are used. A "correction" to a quantity is indicated by adding the letter C to the symbol for the quantity. Likewise, a "rate" or d/dt is indicated by adding the letter R. Precession rates are only indicated by the suffix PR. Occasionally, to avoid confusion and duplication of lettering, a "rate" is indicated by the presence of a dot above the symbol for the quantity.

The suffix "Sig" indicates the error which drives a particular servo, such as "LLG sig." Symbol definitions are based upon the assumption that LBL and VBL are introduced as precession rates. Symbols not used in computer T26 are identified by an asterisk.

A - Target approach angle.

AD - Angle of departure

AK - Basic smoothing constant (AK = .330)
("Aiding Constant")

ALL - Approximate lateral lead (ALL = LL - LLC)

AM - Angular momentum of gyro (AM = Iω)

APV - Average projectile velocity

AVL - Approximate vertical lead (AVL = VL - VLC)

BCV - Ballistic corrections to velocity
(BCV=QECV+WCV+TCV+MVCV)

BPV - Basic projectile velocity

CA - Component angle (between LG and LLG)

CT - Cross tilt

DO - Present slant range

DOR - Range rate

DP - Future slant range

FA - Firing azimuth (as read by dials after orientation)

FE - Firing elevation (with respect to deck)

FT - Forward tilt

GYE - Gyro elevation (GYE = PE - VLG). Also, GYE only equals true gyro elevation (gye) when PEsig = 0 and VLGsig = 0.

KAL - Constant of acceleration feedback in deflection servos.

KFS - Constant in fast settling circuit (KFS = $\frac{4}{3}\frac{PRFS}{LGR}$)

KRL - Constant in rate lag stabilization

KDA - Constant of PA and PE damping circuit

KVC - Constant used in computing VCRF (KVC = a/MV·RD)

L - Lead angle, present to future position

LB - Lateral ballistics lead in LB plane

LBL - Lateral ballistic lead angle in LL plane (LBL = LGBL + LWBL)

LBPR - Lateral ballistic precession rate (LBPR = LGPR + LWPR)

LG - Lead with respect to gyro; gyro deflection

* LGBL - Lateral gravity ballistic lead

LGPR - Lateral gravity precession rate

LGR - Rate of change with respect to time of LG

LL - Lateral lead angle, line of sight to target future position

LLC - Lateral lead correction (from cam)

LLG - Lateral lead, gyro to gun (also called lateral gyro deflection)

LOS - Line of sight

LP - Lateral precession

LPL - Lateral precession lead

LPR - Lateral precession rate at LPR servo (LPR = LPL·RP)

LPRG - Lateral precession rate of gyroscope (LPRG = LPR sec LLG)

LPT - Lateral precession torque

* LRP - RF input to lateral precession torque multiplier ($LRP = \frac{\sin L}{\sin LG} \cdot \cos LG \cdot RF$)

LS - Lateral sight angle, gyro to line of sight.

LSM - Lateral motion of combining glass ($LSM \cong .15\ LS$)

LTG - Lateral torque component perpendicular to gyro spin axis ($LTG = LPT \sec LLG$)

* LWBL - Lateral wind ballistic lead

LWPR - Lateral wind precession rate

MV - Initial muzzle velocity

MVC - Muzzle velocity correction (MVC = MV - 1000 yps)

MVCV - Muzzle velocity correction to velocity

PE - Predicted elevation (from computer)

PL - Precession lead

PR - Gyro line angular rate ("precession rate")

* PRFS - Precession rate of fast settling ($PRFS = PR + \dot{S} - SLR$)

PTI - Projectile time interval

QE - Quadrant elevation (predicted line with respect to gravity) (QE = PE + FT)

QEC - Quadrant elevation correction

QEVC - Quadrant elevation correction to velocity

RC - Slant range at cross-over (RC = Rc)

RCRF - Range correction to response factor.

RD - Relative air density in percent

RF - Gyro response factor rate per unit lead angle

S - Sight angle, gyro to line of sight ($S = AK \sin L$).
SCRF - Smoothing correction to response factor
SE - Scanner elevation (with respect to zero FE line)
SLE - Sight line elevation (with respect to zero FE line)
SLR - Sight line rate (angular)
SRF - Sight response factor ($SRF = RF - SCRF$)
* ST - Settling time
STM - Modified sight line time of flight ($STM = \frac{1}{SRF}$)
T - Fahrenheit temperature
TCV - Temperature correction to velocity
TD - Target dimension
TF - Time of flight
TFR - Time rate of change of time of flight
TG - Torque perpendicular to gyro spin axis
TLL - Total lateral lead angle LOS to Gun ($TLL = LL + LBL$)
TLPR - Total lateral precession rate ($TLPR = LPR + LBPR$)
TM - Modified time of flight
TV - Target velocity
* TVL - Total vertical lead angle ($TVL = VL + VBL$)
* VBL - Vertical ballistics lead angle ($VBL = VGB + VWB$)
* VBPR - Vertical ballistics precession rate ($VBPR = RF \cdot VBL$)
VBS - Vertical boresight deflection
VCRF - Projectile velocity correction to response factor
* VGBL - Vertical gravity ballistic lead angle ("superelevation")
VL - Vertical lead angle, line of sight to future position

VLC - Vertical lead correction (from cam)

VLG - Vertical lead, gyro to gun

VPL - Vertical precession lead

VPR - Vertical precession rate

VPT - Vertical precession torque

* VRF - RF input to vertical precession torque multiplier ($VRF = \frac{\sin L}{\sin LG} \cdot RF$)

VS - Vertical sight angle, gyro to line of sight

VSM - Vertical motion of combining glass ($VSM \cong .30\ VS$)

VT - Computer reference voltage ($VT = V_t$)

VTG - Vertical torque component perpendicular to gyro spin axis ($VTG = VPT$)

* VWBL - Vertical wind ballistic lead angle

WA - Wind angle ($WA = FA - WD$)

WCV - Wind correction to velocity

WD - Wind direction

WV - Wind velocity

Z - Lateral Ballistics factor ($Z = RF \cdot \cos^2 LLG$)

APPENDIX B

A GLOSSARY OF SYMBOLS USED IN ANALYTIC STUDIES OF THE DIRECTOR

37-mm COMPUTER STUDY

a - Retardation coefficient ($secs^{-1}$) for 37-mm, $a = 0.1562 \times 10^{-4}\ RD \sqrt{MV\ (fps)/C_{8.1}}$

Af - True FA = FA - E_{FA}

Ao - True present (observed) azimuth = OA - EA

$C_{8.1}$ - Ballistic coefficient with respect to $G_{8.1}$. Units: psi

DO_{of} - Present slant range at 'open fire'

E - Relative retardation, $secs^{-1}$

E_A - Azimuth tracking error

E_E - Elevation tracking error

E_f - True FE = FE - E_{FE}

E_{FA} - Overall director gun error in azimuth

E_{FE} - Overall director gun error in elevation

E_L - Error in lead angle L

E_N - Resultant maximum error in yards normal to the trajectory

E_N(ptlm) - Resultant maximum potentiometer linearity error in yards normal to the trajectory

E_N(ptrm) - Resultant maximum potentiometer resolution error in yards normal to the trajectory

ε_o - True OE = OE - ε_E

ε_{pr} - Precession rate error

ε_{ptl} - Potentiometer linearity error

ε_{ptlm} - Maximum potentiometer linearity error

ε_{ptr} - Potentiometer resolution error

ε_{ptrm} - Maximum potentiometer resolution error

ε_{RF} - Error in response factor

fps - Feet per second

gye - Actual gyro elevation (GYE + PE sig)

$G_{8.1}$ - Drag function for type 8.1 projectile

K_d - Drag coefficient

m.p.i. - Mean point of impact

mps - Mils per second

OA - Azimuth of director line of sight

OE - Present (observed) elevation, in plane containing LOS and FA axis

p - Heaviside differential operator ($px = \frac{dx}{dt} = \dot{x}$)

psi - Pounds per square inch

pgyl - Position of gyro in lateral plane (90° - LLG - FA Sig)

PCT - Present course time . PCT = Present time minus time at which target reaches present position crossover.

R_o - Ground range

TF_{of} - Time of fight at 'open fire'

TM_{of} - Modified time of flight at 'open fire'

u - (u = APV·DO)

yps - yards per second

APPENDIX C

ILLUSTRATION IDENTIFICATION

Figure	Sperry Print	Figure	Sperry Print
3-1	5282 - 15137	4-1	5282 - 15118
3-2	5282 - 15154	4-4	5282 - 15163
3-3	5282 - 15157	5-4	5282 - 15124
3-4	5282 - 15139	5-5	5282 - 15045
3-5	5282 - 15017	5-6	5282 - 15123
3-6	5282 - 15041	5-7	5282 - 15125
3-7	5282 - 15040	5-8	5282 - 15130
3-8	5282 - 15042	5-9	5282 - 15131
3-9	5282 - 15044	5-10	5282 - 15128
3-10	5282 - 15138	5-11	5282 - 15079
3-13	5282 - 15134	5-12	5282 - 15114
3-14	5282 - 15135	5-13	5282 - 15115
3-15	5282 - 15049	5-14	5282 - 15120
3-16	5282 - 15055	5-15	5282 - 15121
3-17	5282 - 15162	5-16	5282 - 15122
3-18	5282 - 15151	5-19	5282 - 15119
3-19	5282 - 15113	5-20	5282 - 15117
3-20	5282 - 15074		

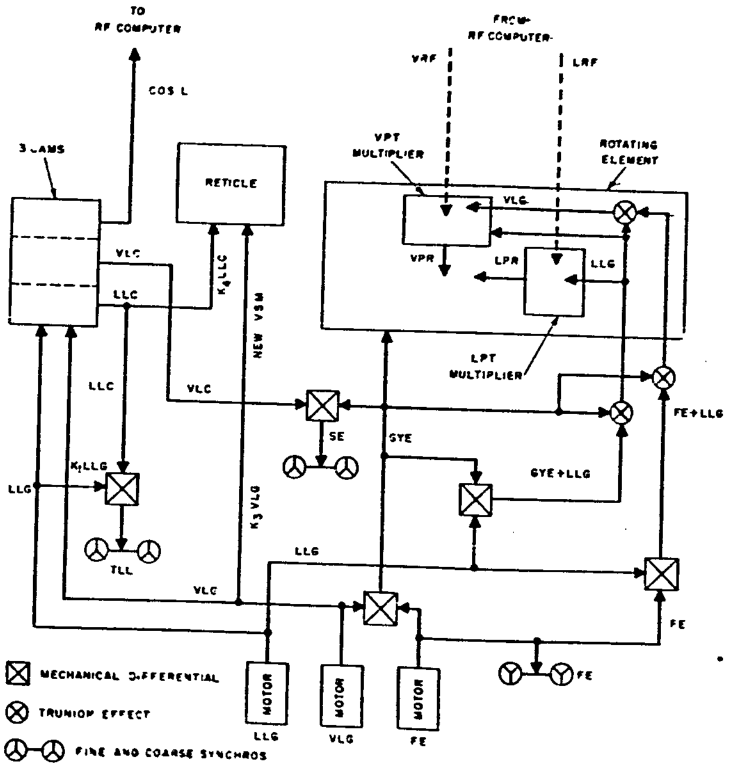

TO
RF COMPUTER
COS L
FROM
RF COMPUTER
VRF
LRF
3 CAMS
RETICLE
VPT
MULTIPLIER
ROTATING
ELEMENT
VLG
VPR
LPR
LLG
LPT
MULTIPLIER
VLC
LLC
K_4LLC
NEW VSM
K_3VLG
SE
SYE
GYE+LLG
FE+LLG
K_1LLG
TLL
FE
MOTOR
MECHANICAL DIFFERENTIAL
TRUNION EFFECT
FINE AND COARSE SYNCHROS

FIGURE 3-1
DATA FLOW OF
MODEL 2 COMPUTER

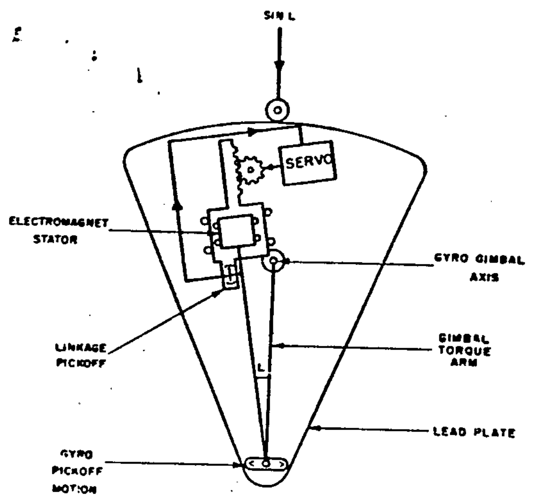

SIN L
SERVO
ELECTROMAGNET
STATOR
GYRO GIMBAL
AXIS
LINKAGE
PICKOFF
GIMBAL
TORQUE
ARM
L
LEAD PLATE
GYRO
PICKOFF
MOTION

FIGURE 3-2
MAGNETIC TORQUE
MECHANISM

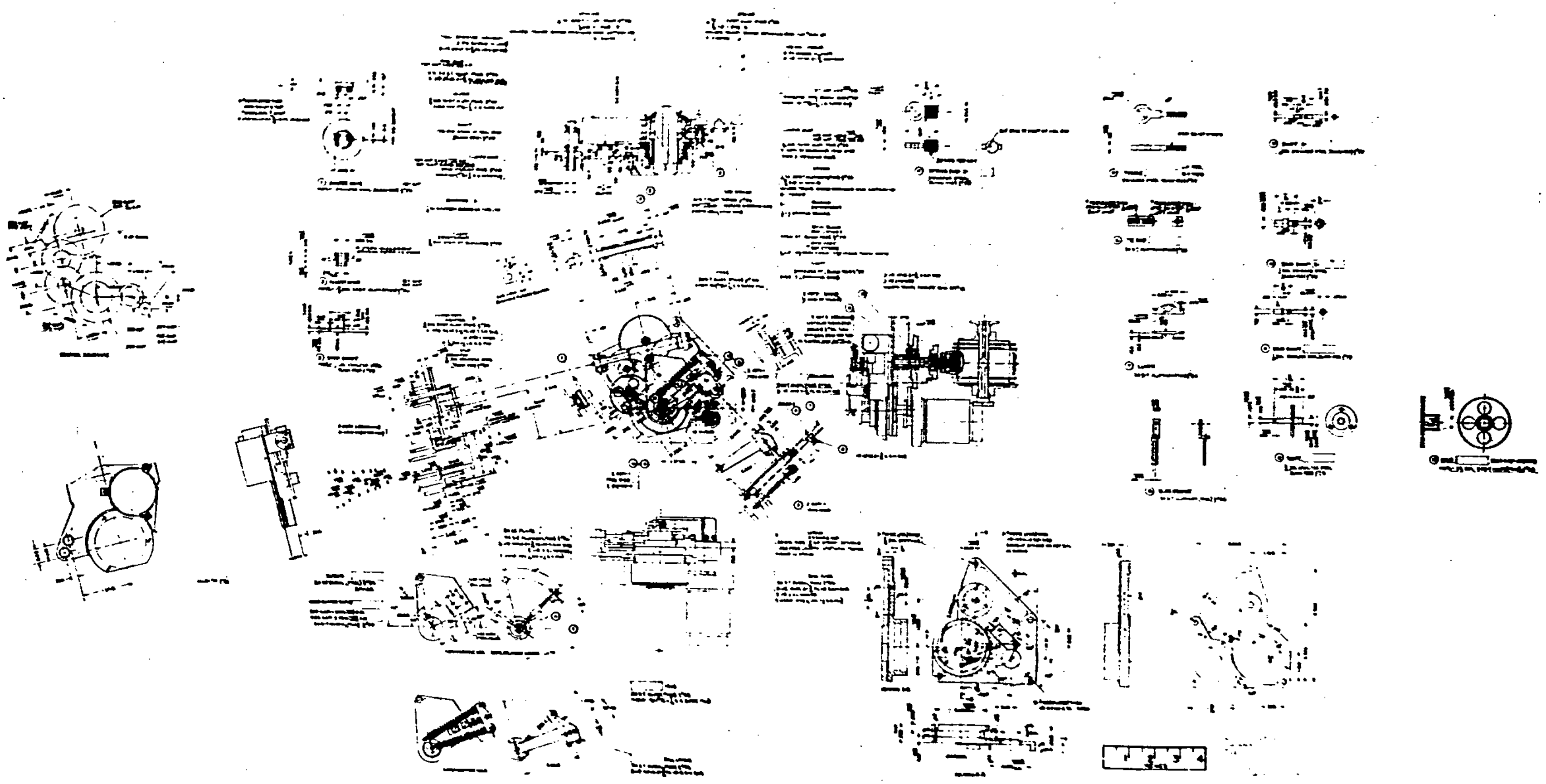


FIGURE 3-3
PRECESSION TORQUE
MULTIPLIER BREADBOARD

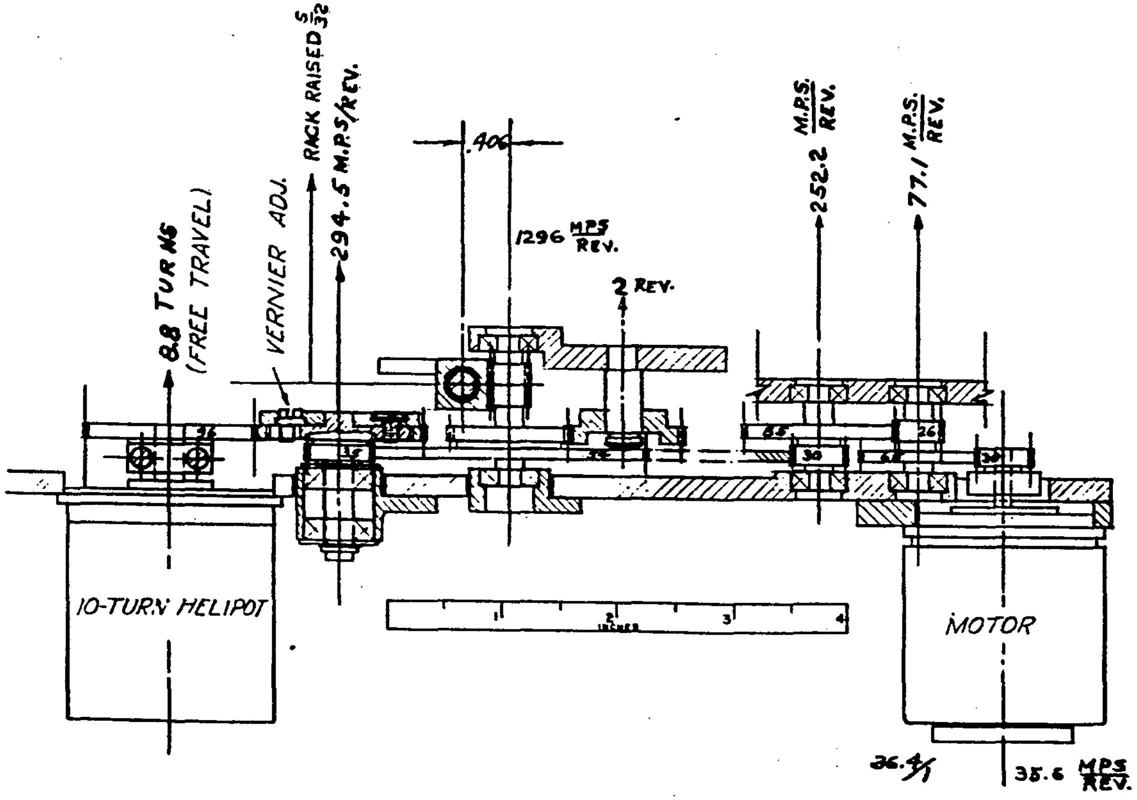

8.8 TURNS
(FREE TRAVEL)
VERNIER ADJ.
RACK RAISED $\frac{5}{32}$
294.5 M.P.S/REV.
.406
1296 $\frac{MPS}{REV.}$
2 REV.
252.2 $\frac{M.P.S.}{REV.}$
77.1 $\frac{M.P.S.}{REV.}$
15
30
26
10-TURN HELIPOT
1
2
INCHES
3
4
MOTOR
36.4/1
35.6 $\frac{MPS}{REV.}$

FIGURE 3-4
PRECESSION MECHANISM-
TEN-TURN HELIPOT MODEL I COMPUTER

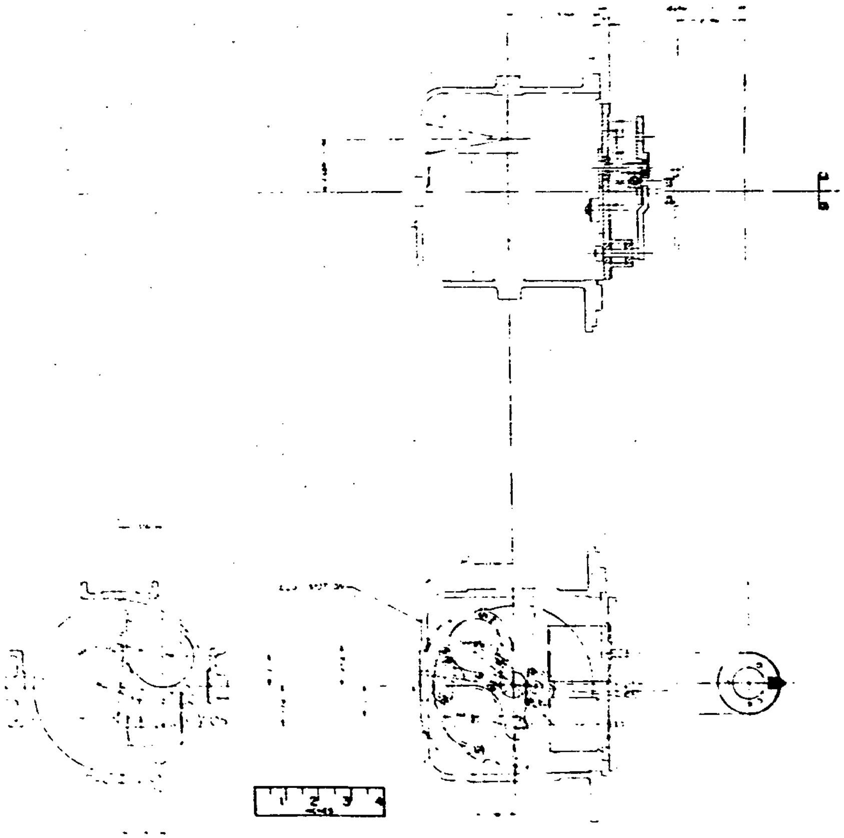


FIGURE 3-5
PRECESSION MECHANISM—
TEN-TURN HELIPOT MODEL I COMPUTER

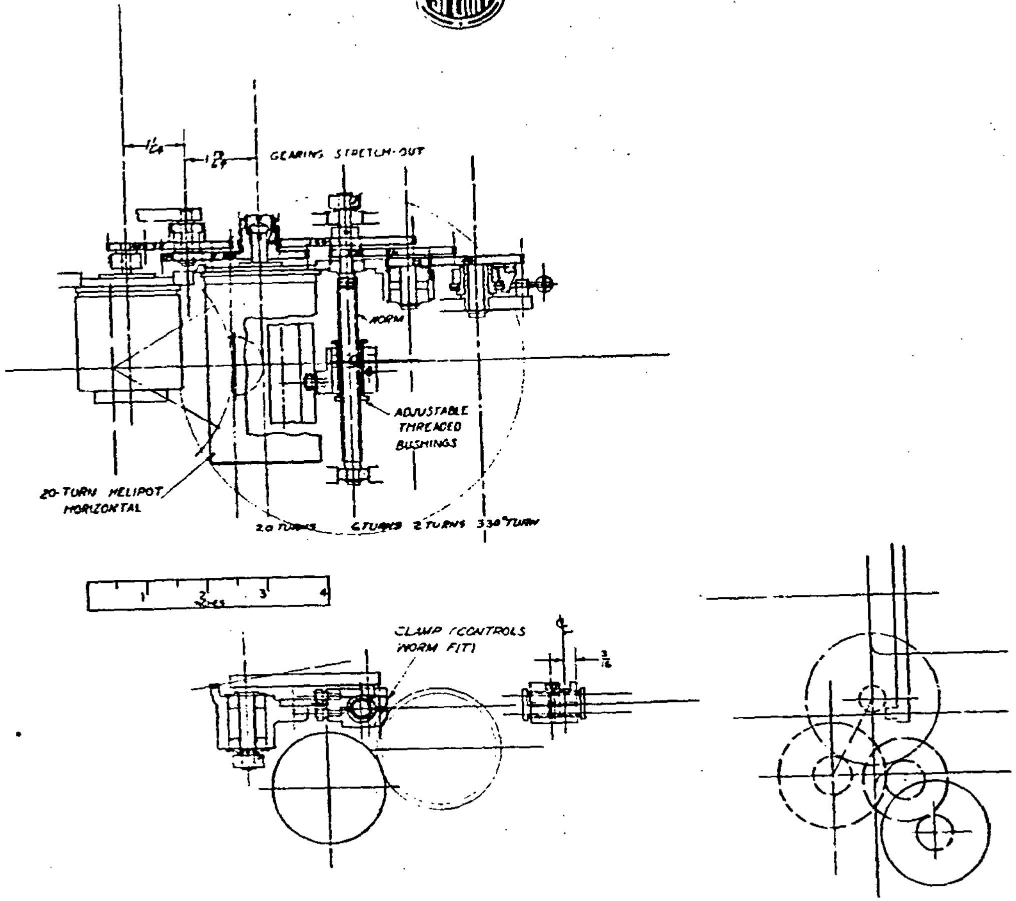
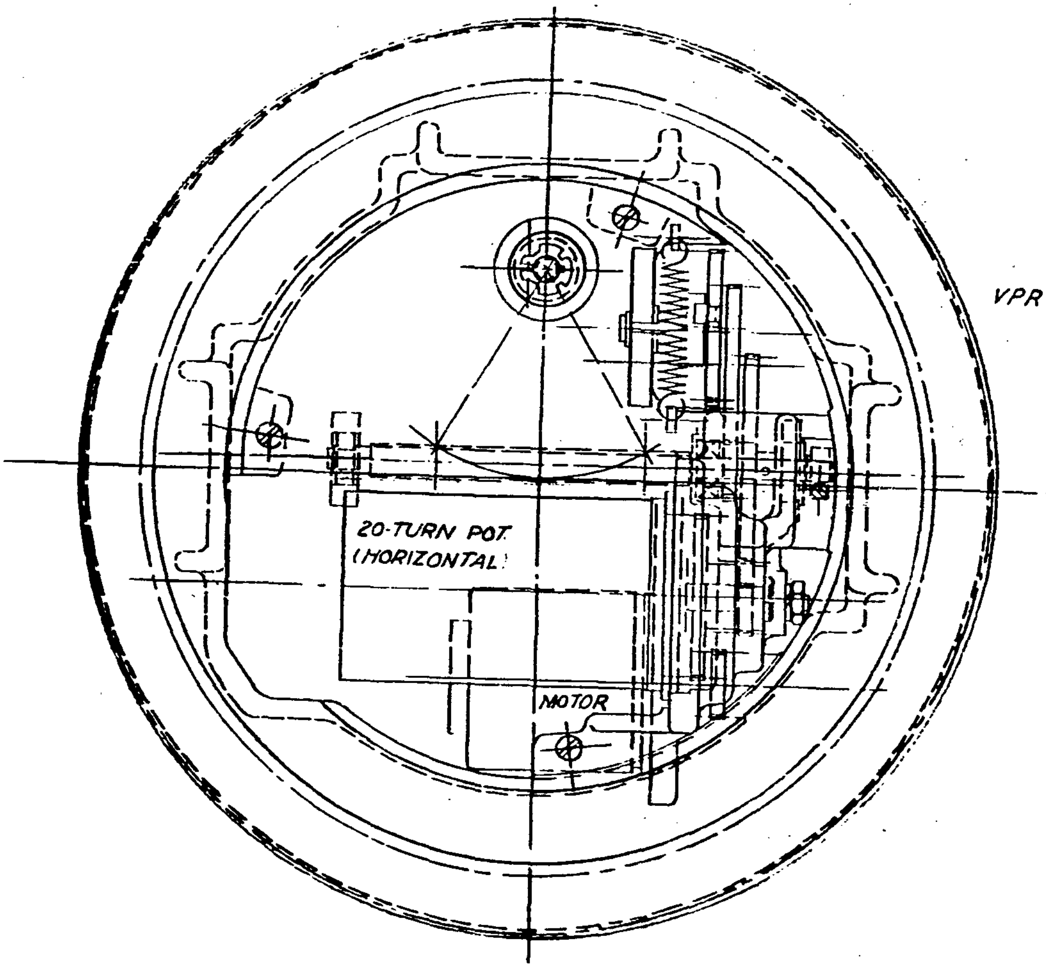

1 1/64
1 13/64
GEARING STRETCH-OUT
WORM
ADJUSTABLE THREADED BUSHINGS
20-TURN HELIPOT HORIZONTAL
20 TURNS
6 TURNS
2 TURNS
330° TURN
1
2
3
4
INCHES
CLAMP (CONTROLS WORM FIT)
3/16

FIGURE 3-6

PRECESSION MECHANISM-
TWENTY-TURN HELIPOT MODEL I COMPUTER


20-TURN POT
(HORIZONTAL)
MOTOR

VPR SERVO

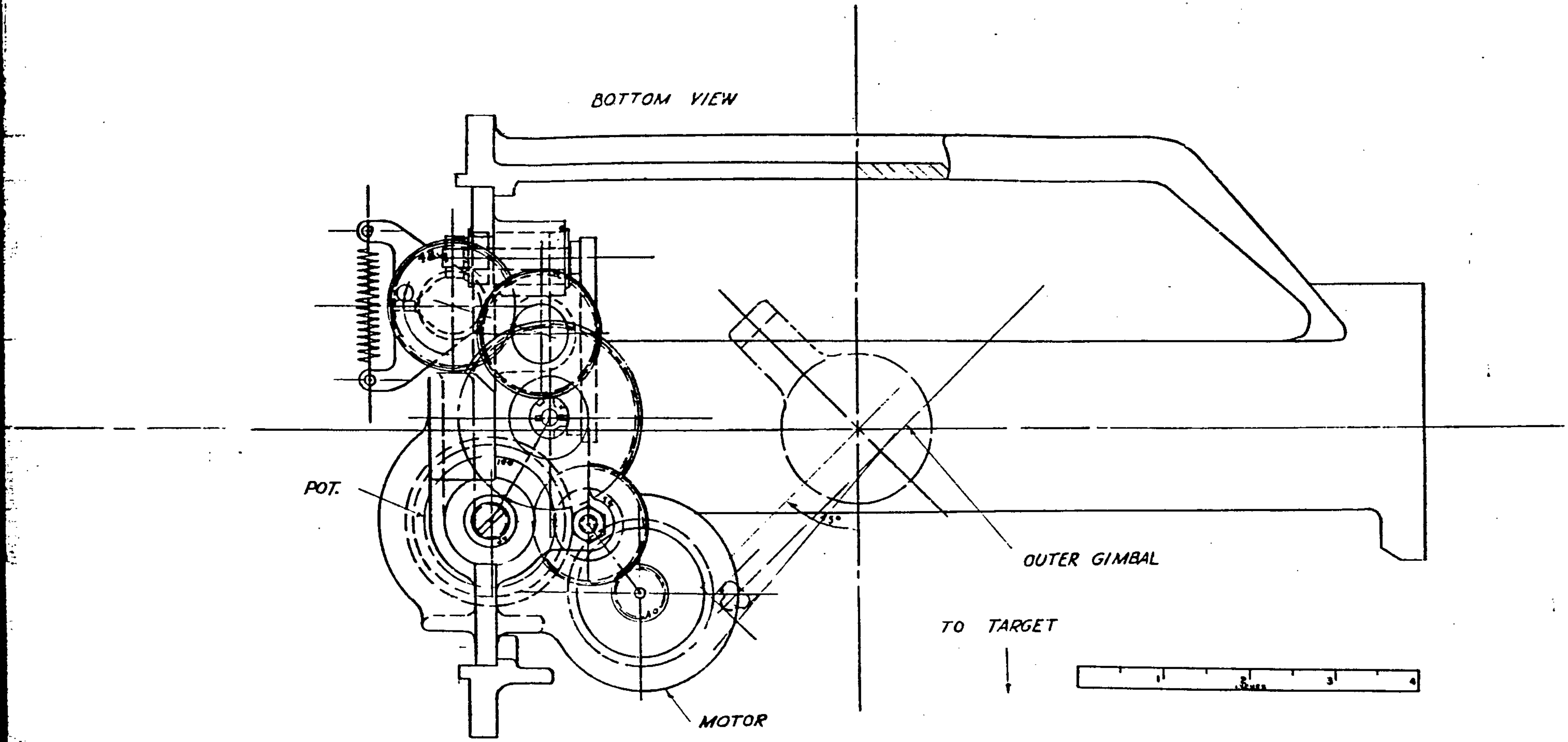

BOTTOM VIEW
POT.
OUTER GIMBAL
75°
TO TARGET
MOTOR
1
2
INCHES
3
4

FIGURE 3-7
LPR MECHANISM
TWENTY-TURN HELIPOT

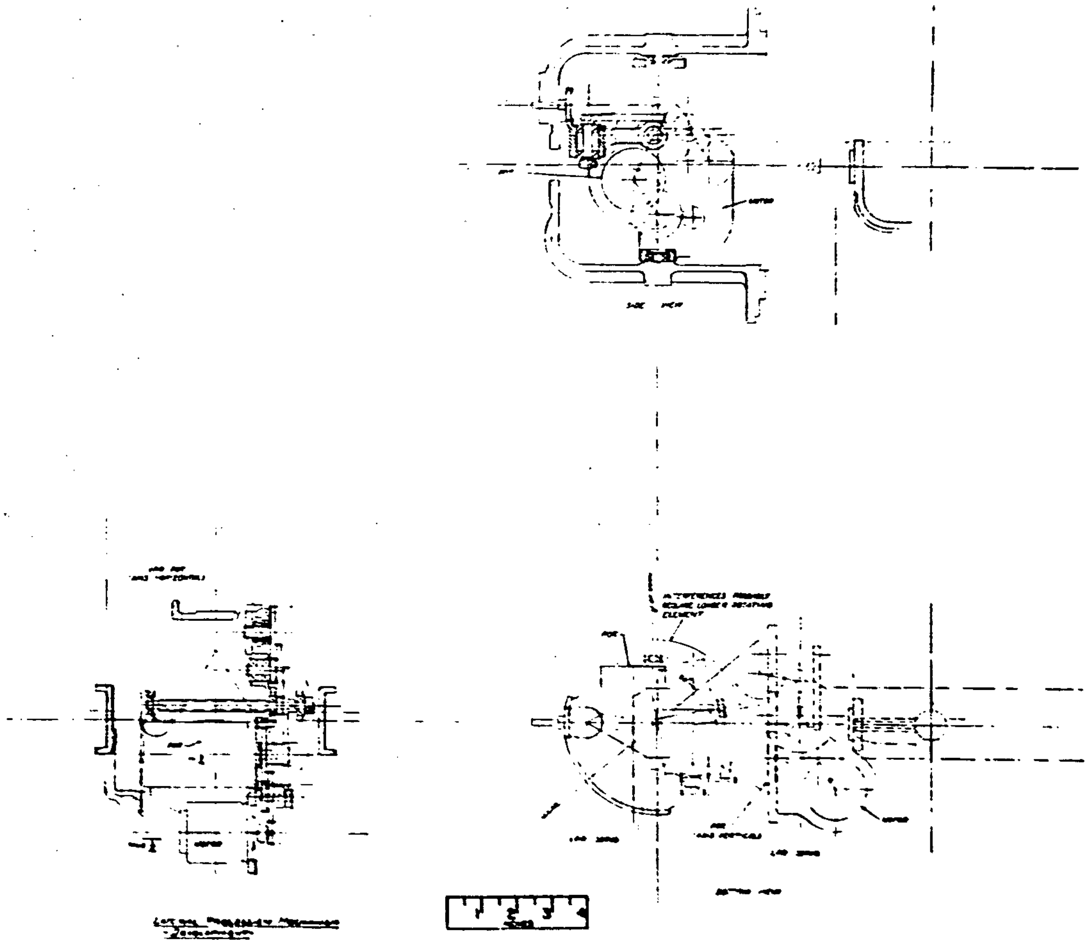

ELEMENT
1
2
3
4

FIGURE 3-8
LPR MECHANISM
TWENTY-TURN HELIPOT

[redacted]

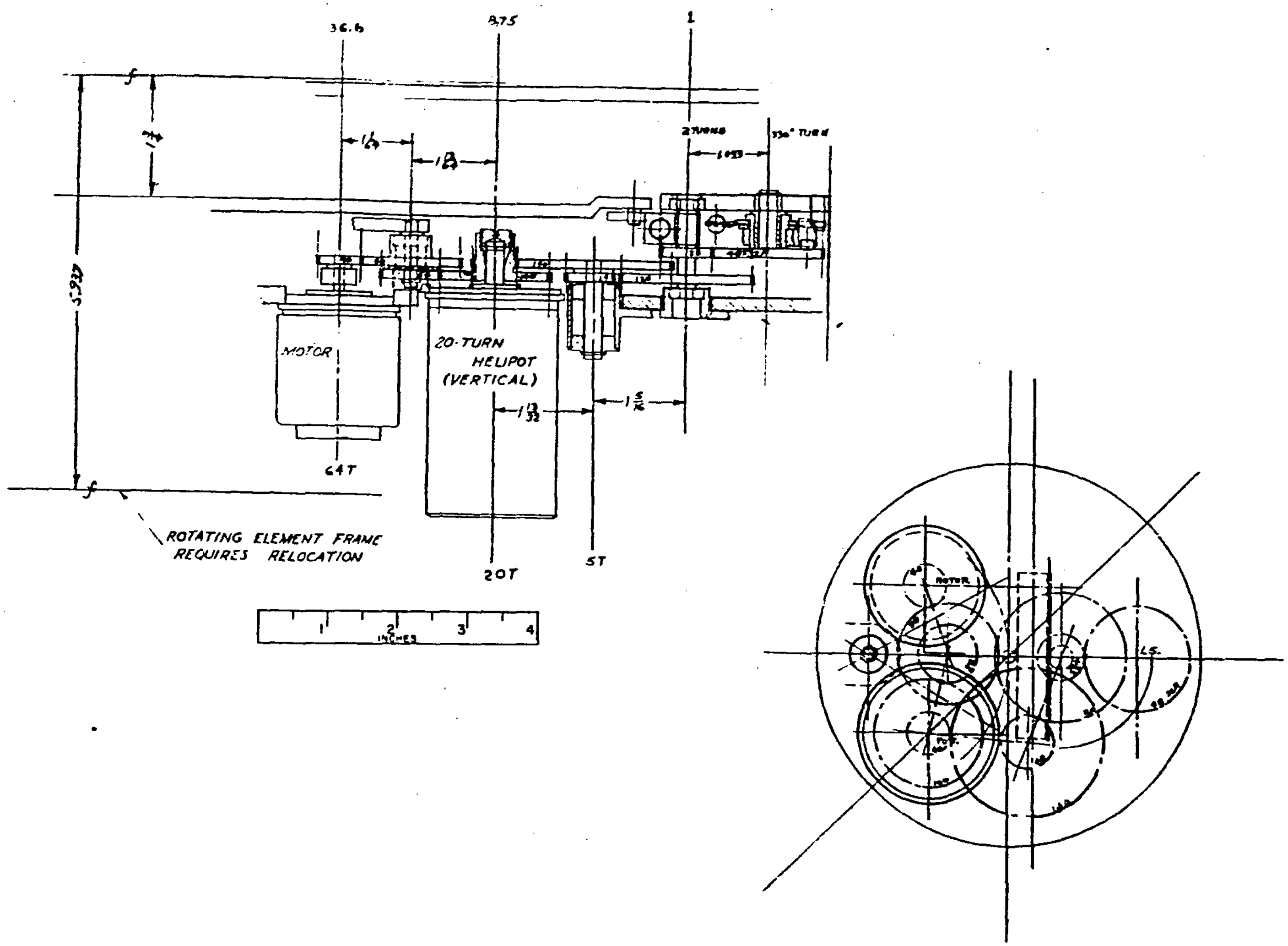

36.6
8.75
1
2 TURNS
330° TURN
1.093
5.937
1 5/16
1 13/32
MOTOR
20-TURN HELIPOT (VERTICAL)
64T
20T
5T
ROTATING ELEMENT FRAME REQUIRES RELOCATION
1
2
3
4
INCHES
ROTOR
POT.
LS.

FIGURE 3-9
POTENTIOMETER
MOUNTING IN VPR SERVO

[redacted]

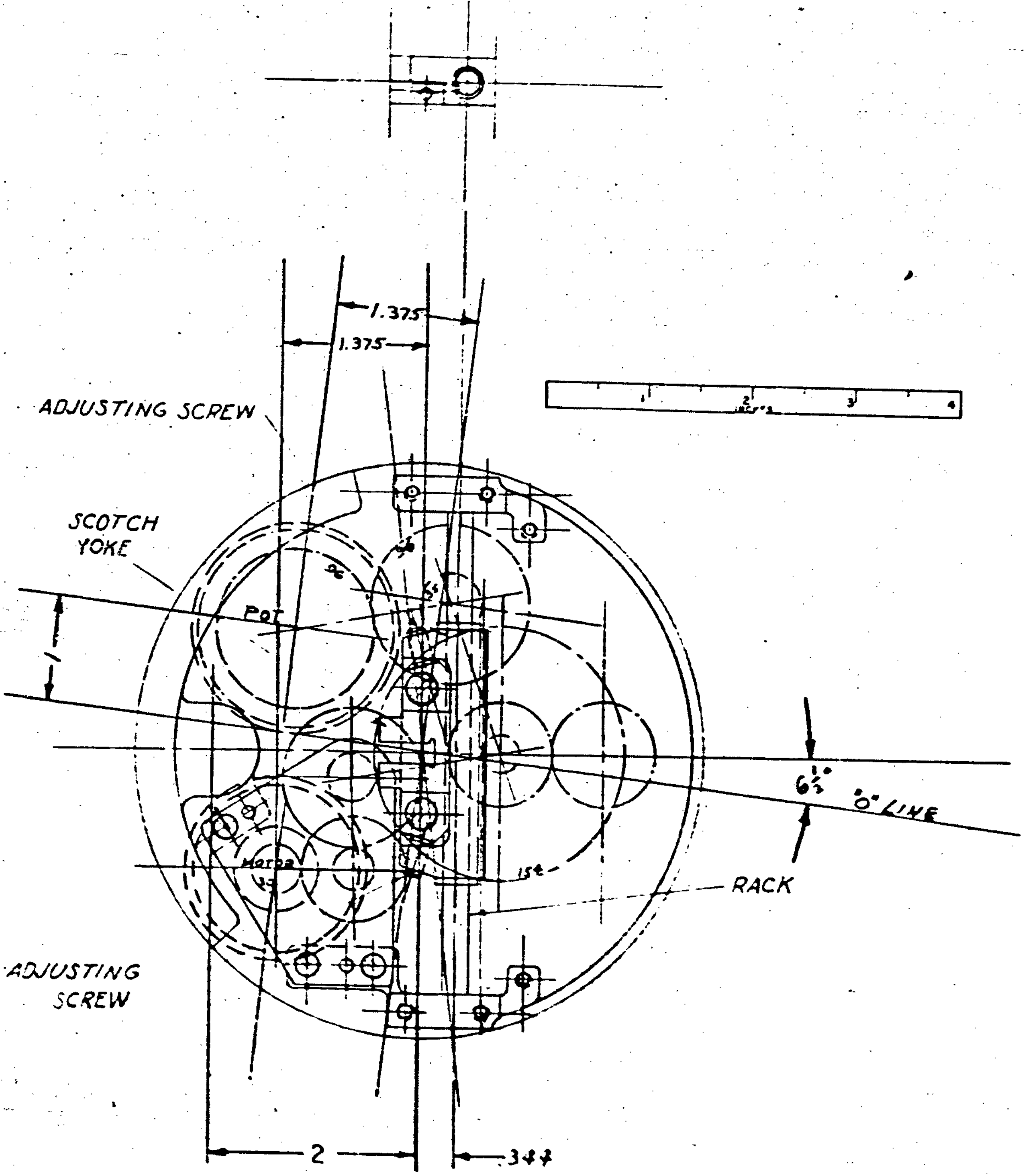

1.375
1.375
ADJUSTING SCREW
1
2
3
4
SCOTCH YOKE
POT
1
6½°
"0" LINE
MOTOR
RACK
ADJUSTING SCREW
2
.344

FIGURE 3-10
ZERO RATE ADJUSTMENT

[redacted]